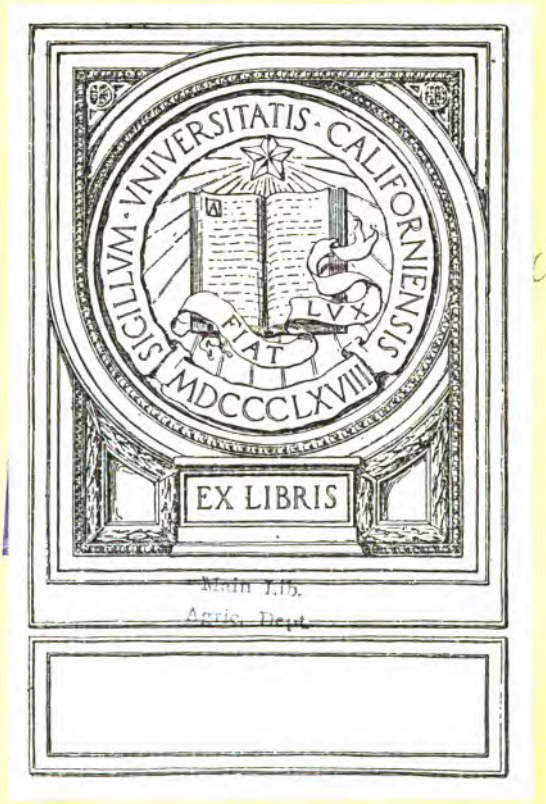
THE

ROTHAMSTED INVESTIGATIONS.



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HISTORY, AND PRESENT POSITION,

OF THE

ROTHAMSTED INVESTIGATIONS.

BY

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APPENDIX.

Rothamsted, June, 1891.

Explanation.

It has now for some time been known that Sir John Bennet Lawes has set apart a sum of £100,000, the Laboratory, and certain areas of land, for the continuance of the Rothamsted Investigations after his death. In furtherance of this object, Trustees were appointed, and the necessary Trust Deed was executed, in February 1889; and, in accordance with the provisions of the Deed, a Committee of Management has been appointed, and has entered upon its duties. The Trustees are, Sir John Lubbock, Bart., F.R.S., Lord Walsingham, F.R.S., and Dr. John Evans, Treasurer of the Royal Society. The Committee consists of nine members:— Dr. John Evans, Treas. R.S. (Chairman), Dr. Hugo Müller, F.R.S. (Treasurer), Professor M. Foster, Sec. R.S., and W. T. Thiselton Dyer, Esq., F.R.S., nominated by the Royal Society; Professor H. E. Armstrong, F.R.S., nominated by the Chemical Society; William Carruthers, Esq., F.R.S., late Pres. Linn. Soc., nominated by the Linnean Society; Sir John H. Thorold, Bart., and Charles Whitehead, Esq., F.L.S., nominated by the Royal Agricultural Society of England; also Sir J. B. Lawes himself.

In view of this new arrangement for the future conduct of the Investigations, it was considered desirable that I should draw up a somewhat detailed account of their history, and their present position; such as might not only aid the members of the present Committee in acquiring a clear view of their objects and scope, but also serve as a permanent record for future reference.

The Report was printed by order of the Committee, and after they had obtained as many copies as they required, they kindly placed the type at the disposal of Sir J. B. Lawes and myself, with permission to make

such alterations as might seem desirable, for wider circulation, especially among those connected with Agricultural Investigation, or Agricultural Education, both in this country and abroad, to whom it is supposed the document may be of interest and utility. Accordingly, some changes in form and arrangement have been made, and the record has been brought up to date, for the purposes of the present issue. With the exception of such changes, the report is essentially the same as that presented, in 1889, to "*The Lawes Agricultural Trust Committee.*"

It should be further stated, that an *Appendix* has been added (pp. 64–74), giving lists of Rothamsted papers already published, arranged in two Series, and within each Series numbered in chronological order. They also show, both where each paper originally appeared, and the date of its publication. These lists are similar to those given in the "*Memoranda*" (see below), and they are given here, not only for purposes of general reference, but especially to facilitate reference to the titles of the papers, or to the papers themselves, which are referred to in the Report under the same numbers as those in the lists.

Introductory Remarks.

I would in the first place say, that the annually published "*Memoranda of the Origin, Plan, and Results of the Field and other experiments conducted on the Farm and in the Laboratory,*" at Rothamsted, gives a great deal of information as to what are the various lines of experiment carried on, and the lists of published papers there given (and in the Appendix hereto), show what subjects have been more or less fully reported upon.

In this annual Memorandum, there is first given a general description of the lines of enquiry in progress, then follow lists of the papers published, with full reference to where they appeared, and then are given summaries, chiefly in the Tabular form, and for the

most part brought up to date, relating to—Rain and Drainage, and to the results of the Field experiments, on Wheat, Barley, Oats, various Root-crops, Potatoes, Rotation, and Permanent Grass; also to Leguminous crops, but so far as they are concerned numerical results are not given. Careful attention should, however, be given to the descriptions, lists, and summaries, in the "*Memoranda.*"

It is to be presumed that the areas of land transferred to the Trustees, indicate pretty clearly the importance to be attached to the various Field experiments which have been carried on, or are still in progress. They are, accordingly, the experiments on—

1. The continuous growth of Wheat, in *Broadbalk Field.*
2. The continuous growth of Barley; also those on Leguminous crops, Wheat alternated with Fallow, and Potatoes, in *Hoos-field.*
3. The continuous growth of Root-crops, in *Barnfield.*
4. Rotation of crops, in *Agdell Field.*
5. Permanent Grass, in *The Park.*

It will be observed that the scheme comprises experiments with individual typical elements of a rotation of crops, namely—wheat and barley representing cereals, various root-crops, and various leguminous crops; also experiments on the crops grown in an actual course of Rotation. Experiments on the mixed herbage of permanent grass-land are also included. Thus, so far as crops are concerned, the characteristic elements of our agriculture are investigated, both as to their intrinsic or individual characters, as shown by their growth year after year on the same land under different conditions as to manuring, and as to their relative or complementary characteristics, as grown in rotation.

After careful consideration of the subject with Sir J. B. Lawes, it was agreed, that the various experiments enumerated, with perhaps the exception of those with

potatoes, must be considered as of substantially equal importance; that is if, as hitherto, questions of fundamental, permanent, and general, as distinguished from those which are of passing, or local, interest, are to be kept in view. It was further considered that, under the same assumption, the laboratory investigations connected with the field results, are not susceptible of any great or material change, or reduction; as the plan and objects supposed, involve the keeping up of the chemical history, both of the experimental crops, and of the soils on which they are grown; and that all that can be done is, to consider what modifications or reductions in the detailed conduct of the different experiments are admissible, or may be desirable, within the comparatively near future, without sacrificing the main objects of enquiry.

In a letter received from Sir J. B. Lawes since the above was written, he says—" * * * looking forward to the great questions which are being raised in regard to exhaustion of soil, and restoration of fertility, I certainly think that our soil samples, and their history, take the first place in importance."

I will now briefly indicate the scope of the investigations, and what has been published, in connection with each of the above enumerated subjects of experiment.

I. The Continuous Growth of Wheat, in Broadbalk Field.

1. *The Field Results.*

The first experimental crop was harvested in 1844, so that the crop of the present year, 1891, will be the 48th. But as the arrangement of the manuring of the different plots was not thoroughly systematised until 1851–52, this is only the 40th year under substantially the same plan as to manuring as now followed.

In the "*Memoranda*" is annually given a statement of the manuring, and of the produce, of each plot, in the

immediately preceding season; also the average produce of each plot over the first half, the second half, and the total period up to date, commencing with the ninth crop, that of 1852. The results so recorded are, however, given numerically only, that is without comment or discussion.

A selection of the results is annually given, and discussed, in a letter published in the chief Daily, Agricultural, and some other Journals, as the basis of an estimate of the average Wheat crop of the United Kingdom.

The field results have been discussed more or less fully, and sometimes in reference to special points of interest, in the papers, the titles of which are given in the list, Series 1 in the "*Appendix*," and there numbered 1, 5, 7, 8, 9, 10, 18, 23, 24, 26, 27, 28, 29, 31, 38, 40, 43, 48, 49, 54, 60, 64, 65, 66, 68, 72, and 73.

The results have been the more fully given, and the more systematically discussed, in Nos. 23 and 66; the first of these giving, and discussing, the results of each of the first twenty, and the second those of each of the second twenty years, of the continuous growth.

It is to be supposed that occasions may arise for partial discussions in reference to special points of interest; but that further systematic discussion will be postponed until the conclusion of the third period of twenty years of the experiments (1903), or possibly only until the conclusion of the first 50 years of their duration (1893).

2. *The Composition of the Continuous Wheat Crops.*

The plots now under experiment are numbered 2 to 20 inclusive; but 3 of these are each divided into 2 separate experiments, raising the number to 22, and 12 of the remainder are each divided into 2, which are now only duplicates, but which have a slightly different manurial history in earlier years, and hence separate samples have hitherto been taken for dry matter, ash,

and nitrogen determinations. There is also one unnumbered plot ("intermediate").

There are thus 19 + 3 + 12 + 1 = 35 samples of grain, and the same number of straw, annually taken. A given weight of each is partially dried, and stored, the grain in bottles, and the straw (cut into chaff) in parcels, for determinations of nitrogen, &c., when required. Duplicate portions of each sample (both grain and straw), are dried in a water bath, and afterwards burnt to ash.

It is desirable to sample the produce as at present, at least up to the end of the 40th year from 1852, namely to 1891 inclusive. But, as 12 of the plots now divided into "*a*," and "*b*," portions, although they have, respectively, a slightly different past manurial history, have for some time been substantially duplicates, it is considered that the two divisions might, after the crop of 1891, be thrown into one, both so far as separation at harvest, and separate sampling, are concerned. These 12 plots are—5*ab*, 6*ab*, 7*ab*, 8*ab*, 11*ab*, 12*ab*, 13*ab*, 14*ab*, 15*ab*, 16*ab*, 17*ab*, and 18*ab*. This would reduce, both the number of plots separately harvested, and the number of samples of corn, and of straw, taken, from 35 each as at present, to 23 each.

The nitrogen is not determined at once, but when needed for purposes of study or publication. Thus, in the case of a selection of plots, the nitrogen has been determined, in the grain and in the straw, of each of the first 20 years of the 48 of the experiments; also in the case of a number of selected plots, in 4 of the same 20 years—representing respectively, two good and two bad seasons. It has been determined in the case of 7 selected plots in proportionally mixed samples of the grain, and of the straw respectively, of the 20 years 1852–71; in the case of 13 selected plots, in proportionally mixed samples of the grain, and in that of 10 selected plots in proportionally mixed samples of the straw, of the 10 years 1852–61; also in the case of the grain of 13 selected plots, and of the straw of 10, for the 10 years 1862–71; and in the case

of 11 selected plots, in the grain for the 10 years 1872–81. Further selections and determinations should be made after the completion of another period of 10 years, that is to 1891 inclusive.

Many determinations of nitrogen, both in the wheat grain, and its Mill products, and also in the straw, are given in No. 10; also in some other papers, and especially in No. 65.

The duplicate ashes are in each case mixed, if the results as to actual and percentage amount are sufficiently accordant; and if not a check quantity of the dry produce is burnt.

From the collection of ashes so obtained, of the grain and of the straw of each plot, in each year, 253 individual, or "*mixed year*," samples have been submitted to complete analysis. Thus, in the case of 3 selected plots, the ashes (of both grain and straw), of each of the last 16 of the first 20 years of the experiments have so been analysed. In the case of 9 selected plots, the ashes of the produce of 4 selected seasons, within the same 20 years, have been analysed; and in the case of 10 selected plots, proportionally made, "*mixed-year*" samples of ash (of grain and of straw respectively), have been analysed for the 10 years 1852–61, and again for the 10 years 1862–71.

In the case of some plots, analyses of the ash of the grain, and of the straw, respectively, representing the 10 years 1872–81, and the 10 years 1882–91 should be made, in continuation of the results already obtained for the two periods of 10 years each, up to 1871 inclusive.

The results of the 253 complete ash analyses already made were published and discussed in 1884, in the paper numbered 65 in the list. The results of many of the nitrogen determinations were at the same time given. A selection of ash analyses, and also many determinations of nitrogen as above referred to, were published in 1857, in the paper No. 10 in the list.

The special object of the selection of plots for the determinations of the nitrogen, and of the composition of the ash, of the produce, has been to ascertain and illustrate

the influence of exhaustion, manures, and variations of season, on the development, and on the organic and mineral composition, of the grain and of the straw, respectively; and the results have proved to be of much interest. It will be observed that nitrogen determinations have been made in selected cases up to 1881 inclusive, but ash analyses only up to 1871. But, as has been stated, samples of the partially dried produce (grain and straw) of each plot, each year, are preserved for future selection for nitrogen determinations or other examination of organic composition, and the ashes are prepared and preserved for future selection for ash analysis, as the progress of exhaustion, or the influence of full supply, may indicate to be desirable.

3. *The Soils of the Continuous Wheat Plots.*

Unfortunately, the conditions of soil-sampling essential to render the analytical results available for the discussion of many important questions, such as that of the soil as a source of the nitrogen of vegetation, and collateral points, which the continuous growth of crops as at Rothamsted suggest, are only learnt by experience, and are perhaps not yet realised anywhere else. Thus, although the Broadbalk field soil was sampled as early as 1846, only a few samples of the surface soil of indefinite area, and of only approximately estimated depth, were taken; so that no acreage calculations can be founded on the results, and no exact comparison made of the condition of the land at that time, and in subsequent years, when more careful samples were taken.

Samples of a definite area and depth were first taken in 1856, but then only of the surface soil, and only from 4 plots; but from 8 places on each plot, a mixture being made of the 8 samples in each case, and in this mixture the nitrogen (by soda-lime), and the carbon, have been determined.

In 1865 samples were taken from 11 plots, from 8 places on each; and in each case representing the

first, the second, and the third 9 inches of depth. In the mixture of the 8 samples from each plot, and to each depth, the nitrogen has been determined, and in some the carbon also. In a few also the nitrogen as nitric acid was determined.

In July 1868, during drought, and in January 1869, when the land was saturated, samples were taken from 3 plots, in each case to 12 depths of 3 inches each, or to a depth of 36 inches in all; and although the chief object was to determine the difference in the amount of water retained on the differently manured plots, at the different depths, the nitrogen, and in some cases the carbon, were also determined.

Lastly, in 1881, samples were taken from 20 plots, in each case from 6 places on the plot, and in each to 3 depths of 9 inches, or to a total depth of 27 inches. In the mixed samples representing, respectively, the soil at each depth, from each differently manured plot, the total nitrogen, the carbon, the nitrogen as nitric acid, and in some cases the chlorine, have been determined. Partial determinations have also been made in a few of the individual or unmixed samples.

The nitrogen results relating to the surface soils, 9 inches deep, of the 11 plots sampled in 1865, were published in No. 57, p. 137 (1881–82). The nitrogen in 10 of these, and in the same 10 in 1881, was given in No. 60, p. 32 *et seq.* (1882).

The nitrogen as nitric acid in the soils was first determined in 1866, in a few of the 1865 samples, and the results were given in the original paper of which No. 25 is the abstract; and referred to in No. 60, p. 48. The nitrogen as nitric acid in the soils of 4 of the 20 plots in which it was determined in the 1881 samples, and at each of the 3 depths of 9 inches each, was given in No. 60, p. 49; and for the whole 20 plots, to the 3 depths, in No. 64, p. 21 and context.

Determinations of nitrogen by soda lime have been made in all the above-enumerated mixed samples of the wheat field subsoils, and the results are of much

interest, as indicating the large amounts of nitrogen they contain; but owing to the great variation in the natural character of the subsoil of one and the same plot at different places, and even at closely contiguous spots, the results are quite inapplicable for comparative acreage calculations, either between plot and plot, or the same plot at different periods, and they have therefore not been published in detail. This great natural irregularity was very marked in the samples above referred to, but it was still more so in the case of some samples taken in 1887 from 3 plots in the same field to the depth of 12 times 9 inches, = 108 inches, or 9 feet, in all; and it has also been very marked in samples taken to a great depth in other fields, as will be referred to further on.

But, notwithstanding this difficulty, the results relating to what may be called the migratory constituents of subsoils, the nitric acid for example, are of great interest and significance. On this ground alone, it is extremely desirable that each of the wheat field plots should be sampled before long—say after the removal of the fiftieth successive crop, to a considerable depth; certainly not less than to 8 times 9 inches, and perhaps to 12 times 9, as has been done in some of the other fields. If, however, the change in the harvesting and sampling which has been above suggested, be adopted after the removal of the crop of 1891, it would be desirable that the soil-sampling should be undertaken after the harvest of that year.

But, independently of determinations of nitric acid, chlorine, &c., and notwithstanding the impossibility, arising from natural irregularity in the character of the subsoils, of judging from determinations of the total nitrogen in them, of the degree in which the subsoils of the different plots, or of the same plot at different periods, have yielded up (or acquired), nitrogen, it is of great importance that samples should in future, as in the past, be carefully taken, and preserved; in the hope that, in the course of time, lines of investigation may be determined upon, which will show the difference, if

any, in the condition of the remaining nitrogen of the subsoils, according to the comparative history of the plots; and so enable a judgment to be formed, of the degree in which the organic nitrogen has already been attacked and has yielded up nitrogen in an available form. It may be that any such method as here supposed, may involve the action of nitrifying, or of other organisms, of solvents, such as acids, and especially organic acids, perhaps determining the character and composition of the matters dissolved, or some quite different method may be indicated, or the difference in the relation of the carbon to the nitrogen, may be found to have significance. But whatever line investigation of the point may indicate, the desideratum is, in defect of trustworthy evidence on the point derived from the determination of the total nitrogen of the subsoils, to determine by some other means, as between plot and plot of known history, or as between the same plot at different periods of its history, whether, and as far as possible in what degree comparatively, the subsoil nitrogen has been subject to loss, or it may be in some cases to gain. It is obviously of interest, too, to endeavour to get a clue to the changes that take place in the mineral composition of the subsoils also.

These points may prove to be of importance so far as the subsoils of the plots which have grown wheat, or other cereals, for many years in succession, are concerned, and especially in the case of those where such crops have been so grown without any nitrogenous manure. But such lines of enquiry, if at all successful, promise much more fruitful results in the case of soils where other crops, and especially where crops of the Leguminous family have grown; whilst those relating to Gramineous crop soils will probably be chiefly of interest in contrast or comparison with those relating to the soils where crops of other families have grown.

At any rate it is essential to bear in mind, that there is nowhere else, such soil and crop history, as at Rothamsted; and that the collection and preservation of samples of the experimental soils, subsoils, and crops,

should not be limited by the exigencies or possibilities of existing lines of investigation or discussion.

I have referred to these points here, as they naturally arise in connection with the question of the wheat field soils and subsoils; but, as has been intimated above, they will probably prove of greater interest and importance in connection with the soils of other crops, and having indicated the points here, I may refer to them more briefly when considering the history of other fields and crops. I have also gone into more detail in regard to other points in connection with the wheat experiments, which, *mutatis mutandis*, will apply to the other fields and crops, and which therefore may be treated more briefly so far as they are concerned.

In conclusion in regard to the wheat experiments, as has been indicated, most of the results relating to the total nitrogen of the surface soils, and most of those relating to the nitrogen as nitric acid, in both surface and subsoils, have already been published; but from what has been said it will be readily understood why the results relating to the total nitrogen of the subsoils have not been recorded, but have only been used as a means of forming approximate estimates of the total amount of combined nitrogen existing to given depths, on a given area.

It should be added that a *résumé*, both of the Field and the Laboratory results relating to wheat, is given in No. 68, published in 1884.

II. The Continuous Growth of Barley, in Hoosfield.

1. *The Field Results.*

The fortieth crop of barley in succession on the same land, without manure, with farmyard manure, and with different chemical manures, is now growing (April 1891). A summary of the results is annually given in the "*Memoranda.*" It will there be seen that

there are 5 main series, of 4 plots each, and there are besides, 9 other plots, making in all 29. The description of the manuring of each plot, given to the left of the columns of figures, taken together with the footnotes, shows the manurial history of the plots from the commencement of the experiments in 1852. As in the case of the wheat, the produce on each plot in the immediately preceding season, also the average produce over the first half, the second half, and the total period up to date, is thus annually given.

In 1857, the results of the first 6 years of the continuous growth of barley, were discussed in the paper numbered 11 in the list (Series 1), and in the same paper the composition of the crops was also considered, so far as the percentages of dry substance, mineral matter, and nitrogen, are concerned.

In No. 33, published in 1873, the results obtained in each of the first twenty years are recorded and discussed, both so far as the influence of season, and that of the different manures, are concerned.

The results obtained with barley were also discussed in regard to special points of interest, in No. 35, published in 1875. Lastly, in 1886, a *résumé* of the results obtained in the 34 years to 1885 inclusive, was given in No. 71, in which tne influences of exhaustion, manures, and variations of season, both on the amounts of produce, and on the composition of the crop, are illustrated.

The second period of twenty years of the barley experiments will be completed with the harvest of the present year, 1891; and the results for that period might suitably be reported upon as soon as the requirements of other subjects on hand will permit. Or some special question may arise requiring partial publication. In the meantime the field results should be annually given in the tabular form in the "*Memoranda*" as heretofore.

2. *The Composition of the Continuous Barley Crops.*

Samples of the grain and of the straw of the barley from each of the 29 plots in Hoosfield are annually

taken. A given weight of each is partially dried for preservation, for nitrogen determinations, or for other organic examination; and duplicate portions are dried at 100°, the dry matter determined and recorded, and then the duplicate portions are burnt to ash, the amounts of ash recorded, and the ashes preserved.

There are practically no duplicate plots; so that, so long as the experiments are continued, there should be very little reduction, either in the separate harvesting, or the separate sampling. After the 40th crop, however, it may be considered whether crop-samples need still be taken from the produce of plots 1N, 2N, 5O, 5A, M, and 6–2, or whether in the case of some of these the sampling might not be discontinued. Samples should certainly still be taken from the grain, and from the straw, of Plots 6–1, 7–1, 7–2, and the other 20 plots. The utmost reduction in sampling that can be suggested is, therefore, from 29 of grain and 29 of straw, as at present, to 23 of each after the 40th crop.

Fewer determinations of nitrogen have been made in the grain and straw of barley than in those of wheat, and most of those which have been made are in "*mixed-plot*" or "*mixed-year*" samples; that is on mixtures made proportionally to the amount of produce in each case, from several plots in one year, or from one plot over several years. The results on the "*mixed-plot*" samples were published in No. 11 as before referred to, but those on the "*mixed-year*" samples have not yet been published, and will probably be reserved until the results of the complete ash-analyses are given in detail.

Complete ash-analyses have been made in the case of 44 grain and 44 straw ashes, selected for the illustration of the influence of exhaustion, manuring, and variations of season, on the mineral composition of the crop; those illustrating the influence of season, being from the produce of individual or mixed plots, in individual years, and those illustrating that of exhaustion and manuring being from "*mixed-year*" samples, covering

consecutive periods of 10, 10, and 5 years, 1852 to 1876 inclusive. Selections from the results of most of these ash-analyses have been published in No. 71 (1886), and they have proved to be of much interest.

It is very desirable that complete ash-analyses, and nitrogen determinations, should soon be made in the case of "*mixed-year*" samples, of the grain and of the straw separately, especially of Plots 2A, and 4A, but also of Plots 1A and 1AA, for the five years 1877–81, for the five 1882–86, and for the five 1887–91 (or for the 10 years 1882–91); in continuation of the results previously obtained for 10, 10, and 5 years (1852–76), as above referred to, for the further illustration of the influence of exhaustion, and of full supply, on the amount, and on the composition, of the produce.

There can be no doubt that it is desirable to continue to take and to preserve samples of the produce of most of the continuous barley plots, and also to determine the amounts of dry matter and of ash, and to preserve the ashes; though, as above suggested, it is a question whether, or when, the sampling from some plots may be discontinued. But here, as in the case of the wheat, it is to be borne in mind that the crop history is unique, and that it is desirable to have the means of reference and selection for the consideration of points other than those which present knowledge and requirement may suggest.

3. *The Soils of the Continuous Barley Plots.*

The experiments were commenced in 1852, but the first soil samples were taken in 1868, and then only from 4 selected plots. Samples were taken at 4 places on each plot, and in each case to depths of 3 times 9 inches, or to a total depth of 27 inches. For each depth, a mixture was made from the samples from the

4 places, and in these mixtures the total nitrogen has been determined by soda-lime.

The same difficulty arose in the application of the results relating to the subsoils, as in the case of the wheat field subsoils, owing to the natural irregularity in composition independently of the special history of the plots; so that only some of the results relating to the surface soils have been published (No. 60, p. 39, 1882).

In 1882, the soils of 26 of the 29 barley plots were sampled, in most cases at 4 or at 3 places, but in a few at only 2 places, on each plot, and in each case to the depth of 3 times 9 inches, or 27 inches in all. A portion of each individual sample is preserved, but mixtures were also made representing respectively each of the 3 depths of each plot. Determinations of nitrogen by soda-lime have been made in the first depth mixtures for each of the plots, and in the mixtures of the second and of the third depth for most of the plots. The carbon has been determined in all the first depth mixtures, and in a few of those for the other depths. Chlorine has been determined in some cases, and the nitrogen as nitric acid at the 3 depths on most of the plots. All the nitrogen as nitric acid results have been published and discussed in No. 64, pp. 28–33, 1883. Some illustrations have been given from the results as to the total nitrogen in the surface soils, but none as to that in the subsoils, nor as yet have any of the carbon or chlorine results been published in detail; but a reference to the carbon results is given in No. 68, p. 24.

If the exigencies of other work permit, it would be desirable to sample the barley soils again after the removal of the fortieth crop (in 1891), that is after the removal of 10 crops since the last sampling; and, as in the case of the wheat field soils, the samples should be taken in most cases to the depth of at least 8 times 9 inches, and in some to 12 times 9 inches; to the greater depth more especially for the determination of nitric acid, and perhaps of chlorine.

III. The Continuous Growth of Leguminous Crops.

1. *In Hoosfield.*

It is a well-established fact in practical agriculture in this country, indeed, in most other countries also, that on only a few soils can a good crop of red clover be obtained, even in rotation, so frequently as once in 4 years, and it is more frequently only grown once in 8 years.

Experiments on the growth of red clover, without manure, and with different manures, were commenced in Hoosfield in 1848–49, and continued up to 1877 inclusive; that is, for a period of nearly 30 years. A chronological account of the experiments, with some reference to the manures employed, and to the crops obtained, is annually given in the "*Memoranda*," but the general results may be briefly stated as follows. In the first year, 1849, heavy crops were obtained on all the plots, and especially with mineral, but without nitrogenous manures; although, compared with crops of the Gramineous and other families, red clover, as well as other Leguminous crops, accumulate a very large amount of nitrogen over a given area.

Much smaller crops were obtained in 1851 and 1852, but since that time nothing like a fair crop has been grown on this ordinary arable land. Indeed, on the greater part of the land, clover was sown 12 times in the 30 years, 1848–77, and more frequently alone than with a corn crop: but in 8 out of the last 10 trials the plant died off in the winter and spring succeeding the sowing of the seed.

The experiments were discussed up to date (1860), in No. 13; and again in 1871, in No. 32; and the subsequent history has been given in the "*Memoranda*"

as above referred to. Further, a summary of the yield of nitrogen has been given and discussed in No. 77, and more details, both as to produce and yield of nitrogen, are given in No. 81.

After the failure of the clover, the land was devoted, in 1878, to the growth of fourteen different plants of the same, that is the Leguminous family, in order to ascertain whether, among those having different habits of growth, and especially different character and range of roots, some could be grown successfully for a longer time, and would yield more produce, containing more nitrogen, as well as other constituents, according to their characters in these respects.

A description, and a brief reference to the results, of these experiments, will be found in the "*Memoranda;*" and the results, so far as their yield of nitrogen is concerned, have been discussed in the paper in the "*Philosophical Transactions,*" numbered 77 in the list; and further results are given in No. 81.

The general result is, that very much more nitrogen has been yielded on this clover-exhausted land, in some of the other Leguminous plants, than in red clover itself. Thus, whilst red clover yielded over 5 years of the 8, 1878–85, when there was any crop, an average of only 22 lbs. of nitrogen per acre per annum, and over the 8 years only 14 lbs., even the weakly growing white clover, which, however, had not been grown on the land for very many years, gave over 6 years of growth an average of 47 lbs., and over 10 years of 28 lbs.; Vicia sativa gave, over 3 years 120 lbs., and over 11 years 77 lbs.; Melilotus leucantha gave, in one year 130 lbs., in another 145 lbs., and over 11 years 62 lbs.; and lastly, the deep and powerfully rooting Medicago sativa gave, in 1 year 337 lbs., in another 270 lbs., in another 247 lbs., and over 9 years an average of 166 lbs. of nitrogen per acre per annum.

It has been decided to consolidate these experiments; in some cases excluding, and in some transferring to another plot, plants which have already more or less failed; and, in most if not all cases, allotting two lands

instead of only one to each description of plant still kept under experiment. The number of different plants will thus be reduced from 14 as originally, to 8 or to only 7. The plan will, however, not be fully developed until 1892, or perhaps a year later.

The samples of produce taken will probably not be much, if at all, reduced, at any rate for some years, as an essential point of interest in the experiments is, to estimate the yield of nitrogen over a given area, by the different descriptions of plant, with their different habits of growth, root-range, &c.

The Soils of the Hoosfield Leguminous Crop Plots.

The very remarkable results obtained in these experiments led to the sampling of the soils of some of the plots to a considerable depth—in fact, to a greater depth than had been adopted in the case of any of the other experimental fields. In March 1881, samples were taken in 5 places on the land where the clover had previously grown, and where no nitrogenous manure had been applied from the commencement, and in each case to the depth of 3 times 9 inches, or 27 inches in all. At the same time, similar samples were taken from the immediately adjoining land which had been devoted to the growth of the Gramineous crop—wheat, alternated with fallow, without any manure, for almost exactly the same period (nearly 30 years), during which the trials with red clover had been made.

In July 1882, after the removal of the crops, samples were taken from the Trifolium repens, and the Melilotus leucantha plots, in each case to the depth of 6 times 9 inches, or in all to 54 inches.

In July 1883, samples were taken from the wheat-fallow, the Trifolium repens, and 2 Vicia sativa plots, now in each case to the depth of 12 times 9 inches, or 108 inches.

Lastly, in July–August 1885, samples were taken rom the wheat-fallow, the Trifolium repens, the Melilotus leucantha, and the Medicago sativa, plots; again in each case to the depth of 12 times 9 inches, or 108 inches.

It was in the case of these Leguminous plant plots, and, for comparison, in that of the alternate wheat and fallow plots, that samples were first taken to so great a depth as 12 times 9 inches; and here the natural unevenness of the subsoils, as observed in other fields to a less depth, was extremely marked. Nevertheless, the determinations of nitrogen as nitric acid at the different depths, on the plots where the different plants had grown, gave results of very great interest. The general result was, that less nitrogen as nitric acid remained in the land to a given depth, the greater the quantity of nitrogen removed in the crops. In illustration it may be stated that, after the Vicia sativa had, over a series of years, yielded much more nitrogen in crops than Trifolium repens, the Trifolium repens soil was estimated to contain per acre to the depth of 12 times 9 inches, or 9 feet, about 146 lbs. of nitrogen as nitric acid; whilst the Vicia sativa soil indicated, in one case only 64, and in another about 55 lbs.; and again, after Medicago sativa had, for some years, yielded very much more nitrogen than Trifolium repens, the soil of the latter contained more than 100 lbs. of nitrogen as nitric acid, but that of the Medicago sativa less than 20 lbs.

A study of the results led to the conclusion, that each of the Leguminous crops had taken up nitrogen as nitric acid from the soil and subsoil, and that the plants which had the greatest root-range had so taken up the most. But, at any rate in the case of the Medicago sativa, the figures did not justify the conclusion that the whole of its nitrogen had been so derived. Assuming that it were not, it is obvious that the deep-rooted plant had either taken up combined nitrogen from the subsoil in some other form, or that free nitrogen had, in some way, been brought under contribution; or

perhaps that each of these sources had contributed more or less to the result.

Owing to the uneven character of the subsoils which has been referred to, it is impossible to determine by the direct or statistical method, whether, or to what extent, the subsoil has lost nitrogen. It is, as has been intimated, in regard to these Leguminous plant-plots, and to the comparison of the condition of the nitrogen in their subsoils with that in Gramineous crop subsoils, and especially in the subsoils of the immediately adjoining unmanured wheat-fallow plots, that the investigation, and settlement, of an indirect method, as suggested at pp. 14–16, would be of very great interest and importance. The samples of subsoil already collected from the Leguminous plant, and wheat-fallow plots, would, if any such indirect method were established, probably yield very fruitful results; but, as time goes on, the character of the subsoils in the two cases will, on the supposition in question, become more and more distinct.

It need only be added in regard to these Leguminous plant experiments in Hoosfield, that so far as the surface soils are concerned, the determinations of nitrogen by soda lime, and so far as both the surface and the subsoils are concerned, the determinations of nitrogen as nitric acid, have already been published and discussed in our paper in the "*Philosophical Transactions*," numbered 77 in the list; and later results are given in No. 81.

It is a question for consideration when, and from which plots, samples of these leguminous plant soils should be again taken and investigated.

The Continuous Growth of Leguminous Crops.

2. *In Geescroft Field.*

This field was devoted to the growth of the Leguminous crop—beans—for a period of 32 years; but owing to frequent failures of the crop, wheat was once taken,

and the land was several times left fallow, during the period.

At the conclusion of the 32 years (in 1878), the land was left fallow until September 1882, when it was sown with grass-seeds, which, however, failed in the winter, and then another Leguminous crop—red clover—which had not been grown on the same land for very many years, was sown (with barley), and it yielded, on this so to speak bean-exhausted land, large crops; which, within a period of about 2 years, accumulated (including a little in the barley) more than 300 lbs. of nitrogen per acre in the removed crops; whilst, at the same time, the surface soil became determinably richer in nitrogen.

This result was obtained, where another Leguminous crop had yielded smaller and smaller crops, where the surface soil was very poor in total nitrogen, very poor in nitrogenous crop residue for nitrification, and the subsoil was, to a considerable depth (72 inches), very poor in ready-formed nitric acid. Here, again, then, satisfactory explanation as to the source of the nitrogen of the crop fails, in defect of evidence as to whether, or in what degree, the subsoil has contributed to the result. In view, however, of recent results, showing the fixation of free nitrogen as a coincident of the development of the so-called "nodules" on the roots of leguminous plants, there can be little doubt that at any rate some of the nitrogen accumulated by the clover after the beans in Geescroft Field, and also of that obtained by the lucerne, and other leguminosæ, grown after the failure of red clover in Hoosfield, was due to the fixation of free nitrogen under such conditions. See Nos. 81, 82, and 84, in the list.

As in the case of other crops, samples of both bean-corn and bean-straw, have been preserved. In all, the dry matter and the ash have been determined; and, in the case of the produce of some plots in a number of individual years, and of some in "*mixed-year*" samples, the nitrogen has been determined. Complete analyses have also been made of 34 corn and 34 straw ashes, representing in each case "*mixed-year*" samples,

corresponding to those in which nitrogen has been determined.

Soil samples were taken from a selection of plots, in 1857 to a depth of 9 inches, in 1865 to the depth of 3 times 9, or 27 inches, in 1874 to the depth of 9 inches, in 1883 to the depth of 8 times 9 inches, and in 1885 to the depth of 9 inches only. The nitrogen by soda-lime has been determined, in mixed samples for each selected plot and depth, and in some individual samples; and in some the nitrogen as nitric acid has also been determined.

Some of the results have been given in No. 67; but more, though still only in summary, in their bearing on the question of the sources of the nitrogen of vegetation, in the paper in the "*Philosophical Transactions*," numbered 77 in the list. The results have, however, been published more fully, so far as they relate to the amounts of produce of the bean and clover crops, and to the nitrogen in them, in No. 81.

It may be added, that after the removal of the clover crops, and the final soil sampling in 1885, the portion of the field that had been under continuous bean crops was fenced off to exclude cattle from it, and it has been left uncultivated ever since. A luxuriant growth of grasses, and other herbage, soon established itself, and this has been left to seed, with the object of ascertaining to what extent the soil will acquire fertility under the influence of the undisturbed natural perennial vegetation. It is doubtful whether it will be worth while to sample the soil at the end of 10 years, that is in 1895, and it may be desirable to let the experiment go on for at least 20 years, and perhaps longer; but the soil should certainly be sampled at the expiration of 20 years, and again at the termination of the experiment if it be continued longer. It should be observed that this portion of land has not been conveyed to the Trustees, but Sir J. B. Lawes leaves a memorandum expressing his wish that the land shall remain at the disposal of the Committee so long as they desire to carry on the experiment.

The Continuous Growth of Leguminous Crops.

3. *In rich Garden soil.*

Some account of this experiment is given in the "*Memoranda*," and the results have frequently been discussed more or less fully in various papers—as for example in Nos. 38, 51, and 60; but they are given in more detail in No. 81.

The experiment was commenced in 1854, and is still in progress, so that this, 1891, is the 38th season of the growth of red clover year after year on rich garden soil. The plots are very small, so that estimates of the amounts per acre, of the produce, or of the nitrogen in it, can only be approximate. The crops are, however, always weighed; samples are always taken for the determination of dry matter, ash, and sometimes nitrogen; and it is estimated that the amounts of produce were, in the early years much more than, over the whole period also more, and, even in many of the later years as much as, is usually obtained on ordinary arable land only once in 4, 6, or 8 years; and the yields of nitrogen in the crops are, accordingly, correspondingly large.

Samples of the soil have also occasionally been taken, and the results point to the conclusion that much of the nitrogen of the clover crops has been derived from the soil.

The plot of land upon which these experiments are conducted, is not transferred to the Trustees, but it is very desirable that they should be continued until decided failure is manifested. The crops should always be weighed and sampled, as heretofore; the dry matter at once determined for the estimation of the crop; the ash also determined; and samples reserved for "*mixed-crop*" and "*mixed-year*" samples, for nitrogen determinations, with a view to the estimation of the yield of nitrogen in the produce. The soils were last sampled in 1879, and it would be of interest again to take samples and determine the nitrogen in them, before

long. Owing, however, to the smallness of the plots, it is undesirable to remove samples frequently; and whether or not any be taken intermediately, they should certainly be taken to some depth, whenever it may be decided to terminate the experiment.

IV. Experiments on the Continuous Growth of Root-Crops, in Barnfield—Common Turnips, Swedish Turnips, Sugar Beet, and Mangel Wurzel.

1. *The Field Results, and the Composition of the Crops.*

These experiments were commenced in 1843, and are still in progress; so that this season, 1891, will be the 49th of their continuance. There was, however, a break after the first 10 years, when, for 3 years in succession, barley was grown, without any manure, over all the plots, in order as far as possible to equalize their condition, due to the previous various manuring, with a view to a more systematic arrangement. Thus, the different crops have already been grown as follows:—

Norfolk White Turnips ..	6 years	1843–48
Swedish Turnips	4 years	1849–52
(Barley without manure) ..	3 years	1853–55
Swedish Turnips	15 years	1856–70
Sugar-beet	5 years	1871–75
Mangel Wurzel	15 years	1876–90

Since the re-arrangement in 1856, there have been about 40 plots, without manure or with different manures. The roots and leaves are always weighed. A sample of the roots is taken from each plot, and of the leaves from a selection of plots. The dry matter and ash are always determined, and partially dried samples preserved for determinations of nitrogen, &c. In each of the 5 years of sugar-beet, the sugar was also determined by polariscope, in 2 of the years in the produce of 40 plots, in 1 year in that of 35 plots, and

in 2 years in that of 30 plots. The sugar was also determined in the produce of the first 5 years of mangel wurzel—in the first year in 20 samples, and in each of the succeeding 4 years in 31 samples.

The results of the first 3 years of the continuous growth of root-crops—1843, 4, and 5—were published, and discussed pretty fully, both as to the amounts of produce, and to its composition, according to the manures employed, in 1847, in No. 2 in the list.

The field results for the 26 years, 1845–70, are summarised in the "*Memoranda.*"

For each of the 5 years of sugar-beet, 1871–75, the produce of both roots and leaves of each plot, the percentages of dry matter and ash in the roots of each plot, of sugar in those of most, and of nitrogen in those of some of the plots, are given in the "*Memoranda.*"

For each of the 15 years of mangel wurzel, 1876–90, the produce of both roots and leaves of each plot is given, and the percentages of dry matter and ash in the roots of each plot, that of sugar in those of most in the first 5 years, and that of nitrogen in the roots of a selection of plots each year, are given in the "*Memoranda.*"

The results, both as to produce and composition of the various root-crops have been discussed in my Oxford Lectures, the substance of which it is arranged shall be published; and a summary of the results was given in No. 76, in 1887.

Analyses have also been made of the ash of the juice of 32 different samples of the sugar-beet.

The present year, 1891, is the sixteenth in succession of mangel wurzel; and unless the crop should signally fail from other than obviously temporary season conditions, it will be desirable to continue the experiments with mangels, which are among the most important of our root-crops, for a fourth period of 5 years, that is until after the removal of the twentieth crop in 1895. After that time, or whenever a change is made, it would be desirable to grow—say 3 crops of barley without manure, clover being sown with the third barley-crop,

and wheat after the removal of the clover, also without manure; in order to gauge, and as far as possible equalise, the condition of the different plots. Experiments might then be re-commenced with mangels, or with some other root-crop.

It is undesirable to reduce the number of samples taken of mangel roots, and mangel leaves, as long as the present arrangement of plots and manuring is continued, as it is very important to keep up the chemical statistics of the crops, and especially the nitrogen statistics. But, if it were considered necessary to reduce the sampling, the most important to continue are Nos. 4, 5, and 6, of each of the five series; and of these the leaves, as well as the roots, should be sampled as at present. Although the leaves of the crop are left on the land, they are always weighed, and it is very important to have the means of estimating the amount of constituents accumulated in the leaves, and how much, therefore, of the constituents of the manure and of the crop, remains as only manure again, under the different conditions as to manuring, and the coincident different conditions of development and maturation.

With a view to the elucidation of the points here referred to, as well as of others, complete analyses of mangel-root-ash, and of mangel-leaf-ash, are specially needed in "*mixed-year*" samples, for the 5 years 1876–80 (or for the 6 years 1878–83—see "Root-crop" Lecture, No. 76, p. 25), and also for the 5 years 1886–90, or at least for one of these periods, for the plots as under:—

Series "O," Plot 4, Plot 5, Plot 6.
Series "N," „ „
Series "A," „ „ „
Series "AC," „ „ „
Series "C," „ „ „

2. *The Soils of the Root-crop Plots.*

Samples of the soil of the root-crop land were collected in 1870, from 35 of the plots, at 4 places on

each, and in each case to the depth of 3 times 9 inches, or in all 27 inches. The nitrogen has been determined in the mixed sample from the 4 holes, for each depth, for each of the 35 plots.

The results relating to some of the surface soils only, have as yet been published (No. 67); and they are of much interest as showing that, under the influence of the growth without nitrogenous manure, of these reputed restorative crops, the surface soil is to a greater extent exhausted of its available nitrogen than by the growth of any of the other experimental crops, even than by the continuous growth of the cereals.

The results relating to the subsoils are subject to the same observations as those obtained with other subsoils, and have not been published.

The soils of the root-crop plots should be again sampled, both for total nitrogen and for nitric acid determinations, whenever the growth of mangel-wurzel is discontinued, and again after the 5 years of the gauge-cropping, as above proposed.

V. The Continuous Growth of Potatoes in Hoosfield.

1. *The Field Results.*

These experiments were commenced in 1876, and are still in progress, so that the crop of the present season, 1891, is the sixteenth in succession on the same land. The series comprises 10 plots. The description and amounts of the manures used (if any), and the amounts of produce, each year, are given in the "*Memoranda.*"

2. *The Composition of the Crops.*

Hitherto, samples have been taken of the "good," of the "small," and of the diseased potatoes, of each plot,

each year. Each year determinations of the specific gravity of the "good" tubers, and of the percentages in them, of dry matter, ash, and nitrogen, have been made, and the results are annually given in the "*Memoranda.*" In the "small" potatoes also, the specific gravity, and the dry matter; have always been determined; in some years the ash, and in one year the nitrogen was also determined; but nitrogen might suitably be determined in "mixed-year" samples only. In the diseased potatoes the dry matter is determined and sometimes the ash.

The dry matter, the sugar, the nitrogen, and the ash have, in selected cases, been determined in the expressed juice of the tubers. In some cases the amount of the nitrogen existing as albuminoids has been determined; and in some complete analyses of the ash, both of the whole tubers and of the juice, have been made. In a considerable number of cases, somewhat similar methods of examination to those adopted in the case of the sound tubers, have been applied to the still white or incipiently diseased, and to the separated discoloured portions, of diseased potatoes. These various results are briefly referred to in the heading to the Tables of composition of the potatoes, in the "*Memoranda;*" and are of considerable importance.

The results of the experiments on Potatoes, both those obtained in the field and in the laboratory, have been pretty fully discussed in my Oxford Lectures; and a *résumé* has been given in No. 78, 1888.

It seems desirable that the sampling of the "good" potatoes, and the determination of their specific gravity, and of their percentages of dry matter, ash, and nitrogen, should be continued so long as the field experiments are maintained. But possibly the sampling of the "small" and "diseased" potatoes, might be discontinued after that of the crop of 1890, which is the fifteenth of the experiments; unless it should be found desirable to follow up any special point in any subsequent year.

VI. Wheat alternated with Fallow, in Hoosfield.

1. *The Field Results.*

From 1851 up to the present time, 1891, one acre has been devoted in Hoosfield to the growth of wheat in alternation with fallow without any manure. This year, 1891, is, therefore, the 41st season of the experiment. In the first year the whole acre was fallow, in the second wheat, in the third fallow, and in the fourth wheat; in the fifth half fallow and half wheat, and this plan has been followed ever since, that is, the crop and the fallow have been alternated on the respective halves each year.

A summary of the crop results is annually given in the "*Memoranda*," and they are there compared with those obtained in the growth of wheat year after year on the same land, without manure, in the immediately adjoining Broadbalk field.

There is only 1 sample of grain and 1 of straw taken each year, and no reduction in the sampling, or in the drying and burning, is recommended; but "*mixed-year*" (instead of individual year) samples, may be made for nitrogen determinations.

2. *The Soils of the Wheat-Fallow Plot.*

Independently of the interest of the crop results as such, the fact that the alternate wheat and fallow plot is immediately adjoining the Leguminous crop plots in the same field, and that from the commencement of the experiments with clover on the Leguminous crop plots the two sets of experiments, the one with a Gramineous crop, and the other with Leguminous crops, have proceeded side by side for almost exactly the same period of time, gives to the soil history of the alternate wheat and fallow plot an especial interest. This point has been referred to already when speaking of the Leguminous crop plots, and, as intimated, the soils of the two sets of plots have generally been sampled at the same

dates, and to the same depths, with a view to comparative results. The results already obtained, especially so far as the nitrogen as nitric acid is concerned, are of much interest; and, as has been said, the further comparative investigation of these adjoining Leguminous and Gramineous crop soils and subsoils, promises, perhaps, more fruitful results, than that of any of the other Rothamsted experimental soils.

Samples of soil were taken from the wheat-fallow plots at 5 places to the depth of 3 times 9, or 27 inches, in 1881; from 4 places to the depth of 12 times 9 inches, or 108 inches, in 1883; and from 3 places, also to the depth of 108 inches, or 9 feet, in 1885. The results of the determinations of nitrogen by soda-lime in the surface soils, and those of nitrogen as nitric acid in both surface and subsoils, have been given and discussed, in more or less detail, in Nos. 62, 64, 67, 77, and 81 in the list.

VII. Experiments on Rotation, in Agdell Field.

1. *The Field Results.*

It will be observed that, in the case of each of the field experiments hitherto considered, the plan has been to grow the same crop year after year on the same land, without manure, and by different descriptions of manure. In those now to be described, various crops are grown in an actual and typical course of rotation, namely, the so-called four-course rotation, of turnips, barley, Leguminous crop or fallow, and wheat. The experiments were commenced in 1848, and are still in progress, so that the crop of the present year, 1891, is the 44th, and the fourth of the eleventh course of 4 years.

One-third of the land has been unmanured from the commencement, one-third has received mineral manure only, and one-third a mixture of both mineral and nitrogenous manure; the manures being applied once in 4 years only, that is for the turnips commencing each course. From half of each of the 3 plots, the turnip-crops

(roots and leaves), are entirely removed, and on the other half they are either consumed on the land by sheep, or cut, spread, and ploughed in. All the other crops are entirely removed from the land. Excepting in the first course of 4 years, when clover was grown as the third crop over the whole of each plot, in the third year one half of each has grown a Leguminous crop (clover or beans), and the other half has been left fallow.

Thus, each of the 3 differently manured plots is divided into 2, so far as the treatment of the turnips is concerned, so making 6; and each of these is again subdivided in the third year, one part growing a Leguminous crop, and the other being fallow, thus making in all 12 plots.

The crop results of these 12 plots, in each of the 43 years now completed, are recorded in the "*Memoranda*" up to date.

2. *The Composition of the Rotation Crops.*

Each year samples of the roots and leaves, or the corn and straw, or of the clover crops, are taken. Portions of each are partially dried and preserved, for nitrogen or other determinations; and portions are fully dried, the dry matter determined, and then burnt to ash, the ashes being preserved.

Very many nitrogen determinations have been made in the produce, sometimes in individual samples, sometimes in "*mixed-plot*," and sometimes in "*mixed-year*" samples. Sixty complete ash-analyses have also been made; chiefly in "*mixed-plot*" or in "*mixed-year*" samples.

3. *The Soils of the Rotation Plots.*

In 1867, samples were taken from each of the 12 plots, at 4 places on each plot, and in each case to the depth of 3 times 9 or 27 inches; and the nitrogen by soda-lime has been determined in the mixed sample from the four holes, for each plot, and for each depth.

In 1874, samples were again taken from each plot, at 3 places on each, and in each case to the depth of 3

times 9 inches, or 27 inches. Nitrogen determinations (by soda-lime) have been made in the mixed samples from the 3 holes, in each case; and the nitrogen as nitric acid has been determined in the soils and subsoils of 6 of the plots.

In the winter of 1883–84, samples were again taken from each of the 12 plots, from 4 places on each plot; and in the case of 2 of the 4 holes only to the depth of 9 inches, but in that of the other 2, to the depth of 12 times 9 inches, or 108 inches in each case. Nitrogen determinations have been made (by soda-lime), in the surface soils, in the mixture from the 4 holes, in a mixture from the 2nd and 3rd holes, and in that from the 1st and 4th holes; also in the subsoils, at each of the 11 lower depths, in the mixture from the 2 holes in each case. In the case of 4 of the 12 plots, the nitrogen as nitric acid has been determined in the mixed sample from the 2 holes, for each of the 12 depths; and in the case of each of the 12 plots, in the mixed samples of the 12th depth; also in a few individual cases. In a few cases the chlorine was also determined.

In the case of these experiments on rotation, it is pre-eminently essential to have the means of tracing the chemical history of the plots, both so far as the crops, and the soils, are concerned. To this end, it is desirable to take samples for dry matter, ash, and nitrogen—of the roots and of the leaves, of each of the 12 plots when under turnips; of the corn and of the straw, of each of the 12 plots when under barley; of each cutting, of each of the 6 plots, when under clover; of the corn and of the straw, of each of the 6 plots when under beans; and of the corn and of the straw, of each of the 12, when under wheat. But, for actual determinations of nitrogen, or for ash-analyses, "*mixed-year*" samples and in some cases "*mixed-crop*" samples, can be adopted.

It would, however, be undesirable to curtail the system of collection and preservation of samples, until the proposed systematic report on the Rotation

Experiments has been published; after which the subject may be re-considered.

Soil samples should probably be again systematically taken at the conclusion of the current rotation—that is in the autumn of 1891, after the removal of the wheat, or, if not then, at the conclusion of the next rotation; for the determination of total nitrogen in the surface soils, and of nitric acid, and perhaps chlorine, in the subsoils to a considerable depth.

Independently of the numerical record of the crop-results given in the "*Memoranda*" as above referred to, and occasional illustrations drawn from them, or from the analytical results, embodied in various papers, the Rotation results as a whole have not been published. They have, however, been arranged, studied, and pretty fully discussed, in 8 of my Oxford Lectures. This discussion includes that of the Field results, the composition of the crops, and the soil results; and, so far as the composition of the crops is concerned, the results of the 60 complete ash-analyses, as well as some others, have been applied. The arrangement, study, and discussion herein involved, is supposed to provide the basis for a systematic paper on the whole of the Rotation results, both crop and analytical; and it is believed that such a paper will prove to be of great interest and importance. It is not intended that any *résumé* of this discussion shall appear before the full paper is published. Such a *résumé* may, however, afterwards be given in the series of my Cirencester Lectures; and it is supposed that the main results will also afterwards be given in the proposed publication of the series of subjects embodied in the Oxford Lectures.

VIII. The Experiments on the Mixed Herbage of Permanent Grass-land. The Park.

1. *The Field Results.*

The majority of these experiments were commenced in 1856, so that the present season, 1891, is the 36th

of their continuance; 4 plots (No. 15, 16, 17, 18) were however, only brought in in 1858, and (Nos. 19 and 20) only in 1872. The total number of plots is now 20, but 3 of these have for many years been divided, making in fact 23 plots in all. During the first 19 years, first crops only were removed as hay, the second crops being either consumed by sheep on the land, or cut and spread upon it. Since that time, second (and sometimes third) crops have as a rule been cut; sometimes removed as hay, and sometimes only cut and spread on the land. Further particulars on these points will be found in the paragraphs at the head of the Table of manures and produce given in the "*Memoranda*."

In the "*Memoranda*" there is annually recorded, the manuring and produce of each plot in the immediately preceding season, the average amounts of produce over the first 10, the second 10, and the first 20 years, from the commencement, when first crops only were removed; also the average amounts of the first crops, the second crops, and the total, over the succeeding years. The description of manures given to the left of the columns, together with the heading and the foot-notes, gives a complete account of the manuring of each plot from the commencement. There is also given a statement of the special treatment of portions of the plots in recent years, by the application of chalk, or of lime, or of both.

2. *The Composition, Botanical and Chemical, of the Crops.*

A sample of the produce of each plot, and of each crop if more than one, is taken each year. A portion of this is preserved for nitrogen determinations, or other chemical examination, and 2 portions are dried at 100°, the dry matter determined, and then burnt to ash, the ashes being preserved.

Nitrogen determinations have been made in the mixed herbage of most of the plots, in most of the years; in a few cases in mixed year samples only; but,

in recent years, in the chalked and limed portions, respectively, of the plots. In the case of selected plots, generally 8 or 9, in 4 years, and once in second as well as first crops, the dry matter, ash, and nitrogen have been determined in the separated Gramineous, the separated Leguminous, and the separated miscellaneous herbage, of the mixed produce.

In selected cases, the "*woody-fibre*," in a given condition of induration, has been determined; and in selected cases also, the proportion of the total nitrogen existing as albuminoids has been determined.

Complete analyses have been made of 145 selected ashes, most of "*mixed year*" samples, some of second as well as first crops, and some of the separated Gramineous, Leguminous, and miscellaneous herbage.

Besides the above-enumerated samples taken for chemical investigation, very numerous samples have been taken for determining the botanical composition of the herbage. Thus, in each of the years 1862, 1867, 1872, and 1877, 20 or more samples were taken, and submitted to complete botanical separation; and for each of these separations the aid of a special assistant was obtained; but the work involved that of one of the Rothamsted staff, and a number of boys also. In 1871, 1874, and 1876, a few samples were taken for partial separation only—that is into total Gramineous, total Leguminous, and total miscellaneous species; and in 1875, and in each year since 1877, from about 10 to 20 or more samples have been taken for such partial separation; all the partial separations being conducted by one of the Rothamsted staff, assisted by a number of boys. In some cases samples from second as well as first crops have been operated upon.

3. *The Soils of the Mixed Herbage Plots.*

In the summer of 1870, which was a period of drought, very variously affecting the herbage of the different plots, samples were taken from 3 of the plots, in each case to the depth of 6 times 9 inches, or to a

total depth of 54 inches. The special object was to determine the difference in the amounts of water at the different depths of the respective plots, with their very varying characters of herbage. In all the samples the nitrogen was also determined.

In 1876, samples were taken from 22 plots, at 3 places on each plot, in each case to the depth of 6 times 9, or 54 inches. Nitrogen determinations (by soda-lime) have been made in the mixed sample from the 3 holes in the case of each plot, and of each depth. Some determinations have also been made in single samples. In many cases the carbon has also been determined, and sometimes both by the combustion and the chromic acid method. In a few cases also the nitrogen as nitric acid was determined.

In 1878, samples were taken from 4 selected plots, from 3 places on each, but to the depth of 9 inches only. In the single as well as in the mixed samples from the 3 holes on each plot, the nitrogen has been determined; the carbon has been determined in the mixed samples, and in one case the nitrogen as nitric acid.

In 1885, samples were taken from 2 selected plots, from 2 places on each, but to the depth of 9 inches only. In the samples from each of the 2 holes the nitrogen has been determined.

In 1886, 12 samples were taken, 5 from one plot, and 7 from another, to the depth of 9 inches only, specially with the view of tracing the connection between the character of the herbage, and the amount of nitrogen in the soils, and the nitrogen was accordingly determined in them.

Independently of the annual record of the crop results in the "*Memoranda*" the results of the grass experiments were reported upon in No. 12, 1858–59, and in No. 19, 1863; botanical and chemical, as well as crop results being considered. But the results for the first 20 years (and in some cases longer), have been much more fully discussed in two papers in the "*Philosophical*

Transactions," No. 50 (1880), and No. 61 (1882). The first of these papers (Part I) treated specially of "*The Agricultural Results*," but involved the use of some of the chemical and some of the botanical data also. In the second paper (Part II) "*The Botanical Results*" were given and discussed in detail. In these papers it is stated that the Chemical Results will be given in a Third Part. This Third Part has not yet been published, but the chemical results have been to a great extent arranged, studied, and discussed, so far as was suitable, in my Oxford Lectures; and it is assumed that this arrangement, study, and discussion, will serve as a basis of a systematic paper constituting "*Part III, The Chemical Results.*" It may be added that the discussion in question includes that of the results of the numerous complete ash-analyses above referred to. Although Parts I and II related mainly to the results of the first 20 years, Part III, which it is hoped will soon be ready for publication, must necessarily include those of later date. It will, indeed, probably include many results up to 1889, and some to 1890, inclusive.

From the foregoing account it will be seen that these experiments on the mixed herbage of permanent grass land, involve a very great deal of work; they do, in fact, involve more than any other equal area of the Field experiments. In the field there are, it is true, no mechanical operations, as in the case of the arable land. But from the complexity of the produce, and the great difference in composition, both botanical and chemical, of the herbage of the different plots, the sampling of the crops, the preparation and treatment of the samples, and the analytical work, both botanical and chemical, take up much time, and employ much labour.

The sampling of the soils, the preparation of the samples, and the determinations of nitrogen, carbon, and nitric acid, in them, have also occupied much time.

Until the whole of the results for Part III have been arranged, and fully studied, it is impossible to decide whether any, or what reduction, in the sampling

of the crops, and of the soils, and in the treatment of the samples, can be recommended. It is possible that some curtailment may be at once admissible; or it may be considered desirable to continue the work on present lines, at any rate until after the conclusion of the second period of 20 years of the experiments, in 1895. It will certainly then be desirable to re-sample the soils of most, if not all, the plots; to a limited depth for the determination of nitrogen by soda-lime, and in selected cases of carbon; also in selected cases, to a considerable depth for the determination of nitric acid, and perhaps of chlorine, and some other constituents. If not before, the system of sampling the crops, both for chemical and for botanical investigation, might at any rate then be fully reconsidered.

Thus far I have given an account of the history and present position, of all those of the Rothamsted Field Experiments which are conducted on the areas of land conveyed to the Trustees; both in regard to the crop results, and to the Laboratory investigations connected with them. I have also described some conducted with Leguminous crops in Geescroft Field, which is not included in the areas set apart for the continuance of the experiments. I should, however, briefly refer to some other experiments that have been made in that field, and also to some conducted in other fields which are not set apart for future experiments.

IX. Experiments on Oats, in Geescroft Field.

The whole of Geescroft Field was devoted to experiments with various Leguminous crops in 1847. The portion on which those with oats were afterwards made, grew clover in 1847 and 1848, beans for 11 years, 1849–59, and then, during 9 years, 1860–68, the land was twice left fallow, grew five crops of wheat without manure, one crop of beans with farmyard manure, and one without manure. The first experi-

mental Oat crop was grown in 1869, and the last in 1878, after which, owing to the wetness and the foulness of the land, it was left fallow for several years, and then the experiment was finally discontinued. The results obtained were, however, sufficient to show the general similarity in manurial requirement of oats and the other cereals, wheat and barley; and although there are obviously points of difference also that it would have been of interest further to investigate, the difficulty of keeping such crops clean when grown year after year on the same land, proved a sufficient obstacle to the continuance of the experiment.

The numerical results of the Field experiments are recorded in the "*Memoranda.*" They have not been systematically discussed in any separate paper; but attention has been called to their more important indications in my Oxford Lectures.

Samples of the produce of each plot, both grain and straw, were taken each year, and the dry matter and ash determined in them. In the case of 3 of the plots, the nitrogen also has been determined, in proportionally mixed samples of the produce (of grain and straw separately), of the first 4 years, 1869–72.

Soil samples were also taken, to the depth of 9 inches only, from 2 of the plots in 1874, which was the sixth year of the experiment; and in these the nitrogen (by soda-lime) has been determined.

X. Experiments on the Alternation of Wheat and Beans, in Geescroft Field.

A portion of the Field, comprising 10 plots, on which peas had been grown for 4 years, 1847–50, was then devoted to the growth of beans and wheat alternately; the respective plots being differently manured for the beans, but unmanured for the succeeding wheat. The experiment was continued without a break for 16 years; and for 12 years more somewhat irregularly, owing to the wetness and foulness of the land; and, for the same

reasons, it was finally abandoned after the bean crop of 1878.

The numerical results of the Field experiments have not been published; but a general statement is given in the "*Memoranda.*" As there stated, the remarkable result was obtained that, without nitrogenous manure, nearly as much wheat, and nearly as much nitrogen, were yielded in 8 crops of wheat grown in alternation with the highly nitrogenous beans, as in 16 crops of wheat grown consecutively over the same seasons, in another field; and also nearly as much as were obtained in a third field, in 8 crops of wheat alternated with bare fallow. Further, the yield of nitrogen in the 8 intermediate crops of beans was, without manure not much less, and with mineral manure more, than in the wheat alternated with them. Thus, as compared with the effects of bare fallow on the yield of nitrogen over a given area, that obtained in the beans was almost entirely clear gain; and the results as a whole afford a striking illustration of the influence of the interposition of Leguminous with Gramineous crops, in augmenting the yield of nitrogen over a given area of land.

Samples, of both corn and straw, of both the wheat and the beans, were always taken, the percentages of dry matter and of ash determined in them, and the ashes preserved. In selected cases, in the earlier years of the experiment, the nitrogen was also determined, in the corn and in the straw, of both crops.

In the autumn of 1857, after the removal of the fourth crop of wheat, surface soil-samples, to the depth of 9 inches, were taken from 4 places on each of 4 of the 10 plots; and at the same time similar samples were taken from 4 plots in the same field, respectively somewhat corresponding in manurial history, but where the Leguminous crop, beans, had been grown year after year without the interposition of wheat. Again, in the autumn of 1865, after the removal of the 8th crop of wheat (alternated with beans), samples were taken from the same 4 plots, and also from the 4 corresponding

continuous bean plots; this time to the depth of 3 times 9 inches, or in all to 27 inches. In all these samples the nitrogen (by soda-lime), has been determined, but none of the results have yet been published. They will probably be most appropriately discussed in connection with the subject of the experiments with Leguminous crops taken as a whole.

In addition to the above, surface-soil samples were taken in 1883, 5 years after the discontinuance of the experiments both with beans grown continuously, and with beans and wheat grown in alternation, and some were also taken in 1885. In all the nitrogen by soda-lime, and in some the nitrogen as nitric acid, has been determined; and a selection of the results has been published. (See No. 67, p. 404; No. 77, p. 21; and No. 81, p. 29.)

XI. Experiments on Barley and Clover, in Little Hoosfield.

These experiments are of considerable interest, but they also have been conducted in a field not set apart for continued investigation.

The field had grown 5 corn crops in succession (1 Wheat, 1 Oats, and 3 Barley), the first without any manure, and the last 4 with artificial mineral and nitrogenous manures, but without any farmyard or other organic manure, up to 1871 inclusive. In 1872 barley was again grown, with artificial mineral and nitrogenous manures; but now the field was divided, and clover sown with the barley on one half. In 1873 barley was again grown on the one half, but clover on the other. The barley yielded 37·3 lbs. of nitrogen per acre, but the three cuttings of clover contained 151·3 lbs. In the next year, 1874, barley was grown on both portions, and on the one where barley had, in the previous year, yielded 37·3 lbs. of nitrogen, it now yielded 39·1 lbs.; but, on the portion where clover had yielded 151·3 lbs. of nitrogen, the barley succeeding it now yielded 69·4. That is to say, the barley yielded 30·3 lbs. more nitrogen

after the removal of 151·3 lbs. in clover, than after the removal of only 37·3 lbs. in barley.

In October, 1873, after the removal of the barley and the clover, samples of soil were taken from 10 places on each of the two portions, in each case to the depth of 3 times 9 inches, or 27 inches. Nitrogen was determined, by soda lime, in the samples from each depth, of 4 of the individual holes separately, and in the mixture of the 4; also for each depth, in a mixture of the samples from the other 6 places. In the first-depth samples the carbon was also determined.

The results showed that the surface soil of the clover land, which had yielded so much more nitrogen in the crops, was nevertheless determinably richer in nitrogen than that of the barley land which had yielded so much less. This was the case, notwithstanding all visible vegetable *débris* had first been removed from the samples. It was further found, that the above and underground vegetable residue, picked from the clover-land samples, was much more in quantity, and contained much more nitrogen, than that from the barley-land samples.

In 1874 and 1875, barley only was sown over both portions. In 1876 barley was again sown over the whole of the land, but with clover as well on the portions where it had been grown in 1873; but the plant failed in the winter, and gave no crop in 1877. In 1877 barley was again sown over the whole, and this time with clover on half of the previously clover portion, and on half the previously only barley portion.

In the autumn of 1877, soil samples were again taken, this time from four places on each of the four differently cropped portions, and in each case to the depth of 6 times 9 inches, or 54 inches. Nitrogen, by soda-lime, has been determined in the mixture from the four holes on each plot, for each depth separately. Nitric acid has been determined, at each depth, in the mixture from the four holes in the case of two of the four plots, and the carbon has been determined in the first depth samples.

The determinations of nitrogen by soda-lime in the surface soils consistently show, as before, a higher percentage where clover had grown than where only barley had grown. As in the case of the subsoils from other fields, the natural irregularities were such that the differences in the amounts of *nitrogen by soda-lime* in the subsoils of the differently cropped portions cannot be referred to the differences in crop history; but, as before pointed out, the significance of the difference in the amounts of *nitrogen as nitric acid* at the different depths is much less affected by the natural irregularities of the subsoil.

The cropping and manuring of this field are still arranged more or less with a view to provide data in reference of the alternation of clover with a cereal, and the amounts of crop are, accordingly, always determined. Owing, however, to the foulness of the land during the growth, and after the removal, of the barley crop in 1890, it was decided to work it, and clean it as far as possible in the autumn, and leave it for summer fallow cleaning in 1891. It is proposed to re-sample the soils of the different plots (especially for the determination of nitrogen and nitric acid), in the autumn of 1891; to sow barley and clover on all four plots in 1892; again to sample the soils after the removal of the clover in 1893; and then probably to discontinue the experiment altogether.

The results of the experiments above described have not been made the subject of a separate report, but abstracts of the numerical results have been given in several papers, and their interest and significance pointed out. (See Nos. 38, 51, 60, 67, and 81.)

XII. Experiments on the Amount, and on the Composition, of Rain, and of Land-Drainage Waters.

The rainfall has been collected and measured at Rothamsted, almost from the commencement of the field experiments; for more than 38 years in a gauge of one-thousandth of an acre area, also in an ordinary funnel gauge of 5 inches diameter; and, commencing

in 1881, in an 8-inch "Board of Trade" gauge as well. At different periods, the nitrogen as ammonia and as nitric acid has been determined in the rain waters. The chlorine and sulphuric acid have also frequently been determined, and sometimes the organic nitrogen.

Three "Drain-gauges," each of one-thousandth of an acre area, have been constructed for the determination of the quantity, and the composition, of the water passing, respectively, through 20, 40, and 60 inches depth of soil, with the subsoil in its natural state of consolidation. These "drain-gauges" have been in operation from September 1870 up to the present time; the soil having been unmanured and uncropped since 1868. In the early years these drainage-waters were only occasionally analysed, the constituents determined being the nitrogen as nitric acid, sometimes that as ammonia and as organic nitrogen, and the chlorine; but from May 1877 up to the present time, the nitrogen as nitric acid, and the chlorine, have been determined in proportionally mixed samples of each month.

Lastly, each of the differently manured plots of the permanent experimental wheat-field (Broadbalk) has a separate pipe-drain, and in December 1866 most of these, and in November 1878 the remainder, were disconnected from the main for the purpose of collecting samples of the drainage water from each, for analysis. In the early years samples were not so regularly taken as subsequently, but from April 1878 up to the present time, they have been collected for analysis on almost every occasion of flow. The late Dr. Voelcker analysed 65 samples of the drainage-waters collected at different periods, in 1866, 1867, and 1868. He determined in them, not only the amount of nitrogen as nitric acid and as ammonia, but he made complete analyses of the mineral matters they contained. Of the samples collected from 1868 to 1873 inclusive, Dr. Frankland made 103 analyses, his determinations having reference chiefly to the amount and the condition of combination of the nitrogen, and to the amounts of carbon and of chlorine. From 1876 up to the present time, the nitrogen as nitric

acid, sometimes that as ammonia, and the chlorine, have been determined at Rothamsted, either in each individual sample collected from each plot, or in mixed samples representing several successive collections, when these have been from continuous, or nearly continuous, rainfalls.

The results relating to the amounts, and to the composition, of Rain and Drainage-waters, are of great interest and importance. Those relating to the amounts of rain, in their bearing on the growth of different crops, have been summarised and discussed in Nos. 1, 2, 31, 39, and 48 (Series 1). The first results relating to the composition of rain-water were published in 1854 in No. 6 (Series 1). Some relating to the composition of the drainage-waters collected in the experimental wheat field are given and considered in No. 33 (1873); and in No. 39 (1876), a summary relating to rainfall, drainage, and composition of drainage, is given. In 1881–82, in No. 57, most of the results obtained up to that date, relating to the amount and composition of rain-water, to the amount and composition of the drainage waters passing through the 20, 40, and 60-inch "drain-gauges," and to the composition of the drainage-waters from the experimental wheat-field plots, are recorded, and discussed in considerable detail; and, in the separate copies of the paper, Appendix Tables are added, which record in detail, the about 1,500 determinations of nitrogen as nitric acid, and of chlorine, respectively, made in the drainage-waters from the differently manured plots in the experimental wheat-field, collected from December 1866 to May 1882 inclusive. Since that date, about 2,000 determinations of nitrogen as nitric acid, and about the same number of chlorine, also occasionally some of ammonia, have been made, in the drainage-waters from the different plots. In No. 63 (1883), new determinations of ammonia, chlorine, and sulphuric acid, in rain-water are given. Lastly, the results as to the amounts of rain, and of drainage through the 20, 40, and 60-inch deep drain-gauges, are given for 20 harvest-years, to August, 1890, inclusive,

in No. 85; they are each year summarised up to date in the "*Memoranda;*" and there are there given, also up to date, the amounts of nitrogen as nitric acid in the drainage-waters.

It is a question whether a summary Table of the amounts of nitrogen as nitric acid, and of chlorine, in the drainage-waters from the experimental wheat-field plots, could not be arranged for publication annually in the "*Memoranda.*" Probably the subject of the amount, and the composition, of rain, and of the various drainage-waters, might, with advantage, be again systematically treated, after a period of about 10 years since the former detailed publication in 1881–82.

XIII. Experiments on the Question of the Fixation of Free Nitrogen.

Experiments were commenced in 1857, and were conducted for several years in succession, to determine whether plants assimilate free or uncombined nitrogen, and also various collateral points.

Plants of the Gramineous, of the Leguminous, and of other families, were grown, in closed vessels, under sterilised conditions, supplied with pure water, washed air, and carbonic acid; in some cases without any supply of combined nitrogen beyond that in the seed sown, and in others with known quantities supplied From the results obtained under these conditions, which were such as to exclude any action either of electricity or of microbes, it was concluded that, under such conditions, our agricultural plants do not directly fix the free nitrogen of the air, either by their leaves or otherwise; and although other experimenters have come to an opposite conclusion from their results, we believe that no evidence of a satisfactory and decisive character has hitherto been adduced, which can be held as conclusive against the view which we have maintained as above stated.

In recent years, however, the question has assumed

quite a new aspect. It now is, whether free nitrogen is brought into combination by the agency of micro-organisms, or other low forms, either within the soil itself, or in symbiosis with a higher plant; thus serving indirectly as a source of nitrogen to plants of a higher order. Considering that the results of Hellriegel and Wilfarth on this point were, if confirmed, of great significance and importance, it was decided to institute experiments at Rothamsted on similar lines. Accordingly, a series was undertaken in 1888; and the results obtained clearly indicated that there was a gain of nitrogen, beyond that supplied in the combined form, in the soil, and in the seed sown. These first experiments were, however, only initiative, and new series were instituted in 1889 and 1890, and some of the biennial or perennial plants are still growing, so that complete quantitative results are not yet available; but there can be no doubt that, in the subsequent experiments, the evidence of fixation will be even more marked than in those of 1888. Obviously such results open a wide field for further investigation; and, accordingly, the enquiry is being continued and extended.

The earlier results obtained on this subject were published, in abstract in No. 14, and in considerable detail in Nos. 17 and 20 (Series 1); and they have frequently been referred to in subsequent papers. Other and more recent results of our own bearing upon the question, as well as those of others published within recent years, have been considered, in abstract in No. 75, and more fully in No. 77. A preliminary notice of the results obtained in the new vegetation experiments was presented to the Royal Society in January 1890, and it is proposed to discuss them and subsequent results more fully, when the whole of the analytical details are available. These recent experiments on the question of the fixation of free nitrogen, were referred to in a postscript in No. 77, also in No. 81; No. 82 gives the "Preliminary Notice;" and No. 84 gives a *résumé* of both the earlier and the later results.

XIV. Experiments on the Feeding of Animals.

The investigations which have been conducted under this head may be conveniently described to a great extent in the terms in which they are referred to in the "*Memoranda.*"

Experiments with the animals of the farm were commenced early in 1847, and have been continued, at intervals, up to the present time.

The following points have been investigated:—

1. The amount of food, and of its several constituents, consumed in relation to a given live-weight of animal within a given time.

2. The amount of food, and of its several constituents, consumed to produce a given amount of increase in live-weight.

3. The proportion, and relative development, of the different organs or parts, of different animals.

4. The proximate and ultimate composition of the animals, in different conditions as to age and fatness, and the probable composition of their increase in live-weight during the fattening process.

5. The composition of the solid and liquid excreta (the manure), in relation to that of the food consumed.

6. The loss or expenditure of constituents by respiration and the cutaneous exhalations—that is, in the mere sustenance of the living meat- and manure-making machine.

7. The influence of different descriptions of food, on the quantity and the quality of the milk yielded by the cow.

The general plan of experimenting was as follows:—

To provide data as to the amount of food, or of its several constituents, consumed in relation to a given live-weight of animal within a given time, and to produce a given amount of increase in live-weight, several hundred animals—oxen, sheep, and pigs—have been experimented upon. Selected lots of animals were supplied, for many weeks or for months consecutively, with weighed quantities of foods, selected and allotted

according to the special point under enquiry. The composition of the foods was determined by analysis. The weights of the animals were taken, at the commencement, at intervals during the progress, and at the conclusion, of the experiment.

The amount, and the relative development, of the different organs and parts, were determined—in 2 calves, 2 heifers, 14 bullocks, 1 lamb, 249 sheep, and 59 pigs.

The percentages of water, mineral matter, fat, and nitrogenous substance, were determined in certain separated parts, and in the entire bodies, of 10 animals; namely, 1 calf, 2 oxen, 1 lamb, 4 sheep, and 2 pigs. Complete analyses of the ashes, respectively, of the entire carcasses, of the mixed internal and other "offal" parts, and of the entire bodies, of each of these 10 animals, have also been made.

From the data thus provided, as to the composition of the different descriptions of animal, in different conditions as to age and fatness, the composition of the increase whilst fattening, and the relation of the constituents stored up in increase to those consumed in food, have been estimated.

To ascertain the composition of the manure in relation to that of the food consumed, oxen, sheep, and pigs, have been experimented upon.

In the case of oxen, the food and litter (sometimes with an acid absorbent) were weighed, sampled, and analysed. The animals were fed in boxes for periods of from 5 to 9 weeks, and the total manure produced was well mixed, weighed, sampled, and analysed. The constituents determined in the food and litter on the one hand, and in the manure on the other, were dry matter, ash, and nitrogen.

In the case of sheep no litter was used; the animals were kept in lots of 5, on rafters, through which (but with some little loss) the solid and liquid excreta passed on to a sheet zinc flooring, at such an incline that the liquid drained off into carboys containing acid, and the solid matter was removed 2 or 3 times daily;

and also mixed with acid. The constituents determined in the food and manure were dry matter, mineral matter, sometimes "woody-fibre," and nitrogen.

In the case of pigs, individual male animals were experimented upon, each for periods of 3, 5, or 10 days only. Each animal was kept in a frame, preventing it from turning round, and having a zinc bottom with an outlet for the liquid to run into a bottle, and it was watched night and day, and the voidings carefully collected as soon as passed. This could easily be done, as the animal never passed either fæces or urine without getting up, and in getting up he rang a bell, and so attracted the notice of the attendant. The constituents determined were, in the food and fæces, dry matter, ash, and nitrogen, and in the urine, dry matter, ash, nitrogen, and urea.

The loss or expenditure of constituents by respiration and the cutaneous exhalations has not been determined directly, that is by means of a respiration apparatus, but only by difference, that is by calculation founded on the amounts of dry matter, ash, and nitrogen, in the food, and in the (increase) fæces and urine.

Besides the special experiments which will be presently referred to, made to determine the influence of different foods on the quantity and composition of milk, a careful daily record has been kept for several years, of the morning and evening yield of each individual, of a herd of between 40 and 50 cows, regard being had to the amount of food consumed, which in its turn has been to a certain extent graduated according to the yield.

Independently of the points of enquiry above enumerated, the results obtained in the feeding experiments have supplied data for the consideration of the following questions:—

1. The sources in the food of the fat produced in the animal body.

2. The characteristic demands of the animal body (for nitrogenous or non-nitrogenous constituents of food), in the exercise of muscular power.

3. The comparative characters of animal and vegetable food in human dietaries.

The results of the above described very comprehensive and very laborious experiments on the feeding of animals, involving an elaborate investigation into the composition of the animals fed and slaughtered as human food, in different conditions as to age and fatness, have, excepting so far as the composition of the manure in relation to the food consumed is concerned, been published in detail in the various papers enumerated in the list "Series 2" in the Appendix.

Twelve of my Oxford Lectures were devoted to the subject of the feeding of animals, for the production of meat, milk, and manure, and for the exercise of force. In the course of these lectures, the hitherto unpublished results as to the composition of the manure in relation to that of the food consumed, were arranged, studied, and more or less discussed, and thus the basis of a systematic paper on the subject has been provided.

XV. Supplementary Investigations in Connection with the Subject of the Feeding of Animals.

1. *Experiments on the Utilisation of Town Sewage.*

In 1861, 1862, and 1863, an extensive investigation was undertaken, in conjunction with the late Professor Way, on behalf of the Royal Sewage Commission, of which Sir J. B. Lawes was a member, on the application of town sewage to different crops, but especially to grass. The amount, and the composition, of both the sewage applied, and the produce grown, were determined; and, in selected cases, the composition of the land-drainage waters was also determined. Comparative experiments were also made on the feeding qualities of the differently grown produce; the amount of increase yielded by oxen, and the amount and the composition of the milk yielded by cows, being determined. A large amount of the analytical work involved was executed at Rothamsted, but most of it by Professor Way, in London.

The results of these enquiries were published in full in No. 21, and less fully in No. 23, on the Composition, Value, and Utilization of Town Sewage. The subject has also been discussed in Nos. 8, 9, 19, and 26 (all in Series 2).

2. *Experiments on the Malting Process, and on the Comparative Feeding Value of Barley and Malt.*

The chemistry of the malting process, the loss of food constituents during its progress, and the comparative feeding value of barley and malt, were made the subjects of independent experiment at Rothamsted in 1848 and 1849; and in 1863 and 1864, a more comprehensive investigation was undertaken by order of the Board of Trade. The earlier results were discussed in Nos. 1, 4, 12, and 13, and the later in No. 22 (Series 2).

3. *Experiments on Ensilage.*

Experiments were commenced in 1884, and continned for several years, to determine the changes and losses which food-crops undergo in the process of ensilaging, and also the feeding value of the silage produced. With these objects two silos were constructed.

In the first season, 1884, one silo was filled with first and second crop red clover, and the other with first crop meadow-grass, second crop red clover, and second crop meadow-grass.

In the second season, 1885, Silo No. 1, was partly filled with oats cut green, when the grain was in the milky condition, and partly with second crop red clover: and Silo No. 2 with first and second crop red clover.

In the third season, 1886, first crop meadow-grass was put into Silo No. 1; and into Silo No. 2, first crop red clover, a mixed crop grown for the purpose, consisting of beans, peas, vetches, and oats, and second crop red clover.

In the fourth season, 1887, a similar specially grown mixed crop of beans, peas, tares, and oats was put

into Silo No. 1, but nothing into Silo No. 2; which, however, still contained some of the first crop red clover put in in 1886.

In the fifth season, 1888, meadow-grass, and half-made meadow-hay, were put into Silo No. 1, and into Silo No. 2, a similar mixed crop as in previous years, also some lucerne, meadow-grass, barley cut green, and red clover. Part of these remaining unconsumed during the summer of 1889, and the season having been very favourable for hay making, nothing more was put into either silo in that year (1889). Nor was any of the 1888 silage taken out of Silo No. 1 in 1890, but in the wet July of that year, the pit was filled up with half-made spoiling hay, without weighing or sampling, and the whole has been used without weighing or sampling, so that no experimental results will be available in regard to the contents of Silo No. 1. From Silo No. 2, however, the 1888 silage was removed from January to May 1890, the whole being weighed and sampled, so that the results will be available for purposes of calculation. Subsequently, in the summer of 1890, Silo No. 2 was also filled with half-made spoiling hay, without weighing or sampling.

For purposes of experiment, the weight of each description of produce is taken, both when put in and when taken out of the silo, and samples, both of the produce as put in, and of the silage taken out, are taken. In these, the dry matter, ash, and nitrogen, are always determined. In the silage, in some cases, there have also been determined, the amounts of albuminoid nitrogen, of soluble and insoluble nitrogenous substance, of soluble and insoluble ash, of cellulose of a given degree of solubility, assumed to be digestible, and of the remaining "woody fibre," assumed to be indigestible (though in reality largely digestible by ruminants), also the amounts of acetic and lactic acids.

The general result is, that the loss of organic substance in the process of ensilaging is exceedingly variable, according to the description of the herbage, its condition of succulence or maturity, and other circum-

stances. The loss has, in only a few cases been but little more than in the hay-stack, and is generally very much more. There has always been a considerable, and sometimes a very considerable, loss of total nitrogen; and there is, besides, a considerable amount of degradation from the albuminoid condition to compounds of lower, if of any, food-value. Nor do the results afford any evidence that "woody-fibre" of a given degree of induration is rendered more soluble, and consequently more digestible.

Experiments have also been made, to determine the value as food, of different descriptions of silage, compared with that of other ordinary food-stuffs. Thus, trials have been made—with red clover silage against a mixture of red clover hay and Swedish turnips—in each case given, with fixed amounts of other foods, to fattening oxen; with red clover and meadow-grass silage, against mangels, each given, with fixed amounts of other foods, to milking cows; with silaged green oats against ripened oats (grain and straw), given, with other foods, to fattening oxen; and with meadow-grass silage against corresponding meadow-grass hay, given, with other foods, to fattening oxen.

So far as it is possible to state the result of the feeding experiments in a few words, it may be said that silage, properly made, of good materials, is undoubtedly a good food. But how far it is economical must largely depend on at what cost of loss it has been produced; for, so far as can be judged from the results obtained hitherto, its value, compared with that of fairly comparable foods, depends, at any rate for fattening animals, on the amount of digestible dry substance which it supplies; and, as has been stated, the amount of this which is lost in its production is very variable, and much has still to be learnt as to the conditions under which more or less is so lost; whilst it would seem that, of the constituents which remain, the digestibility and assimilability of the non-nitrogenous are not increased, and those of the nitrogenous are reduced. For milking cows also, silage, given in limited quantity, is a good food. But, independently of the amounts

of loss or degradation of constituents above referred to, it seems to be less appropriate for them than the usual more succulent foods, both so far as the flow of milk, and its quality, are concerned. The important questions as to the effect which the extensive adoption of ensilaging would have on the cropping and general economy of the farm, cannot be referred to here.

The results of the first season's experiments, those of 1884–85, both as to the changes and loss in the production of the silage, and as to the feeding experiments, have been given, and pretty fully discussed, in No. 30, Series 2. Those obtained in the second season have been published in the "*Agricultural Gazette*," both so far as the production of the silage and the feeding experiments are concerned. But the results, both as to the silage-production, and as to the feeding experiments, of subsequent seasons, remain to be considered. The hitherto unpublished results would form the subject of an important contribution to existing knowledge on the ensilage question, whenever the pressure of other subjects may permit of time being devoted to it.

The Silos will probably be used whenever the characters of the season are such as to render it desirable or convenient to preserve forage crops in that way. But further experiments on the production and use of silage are for the present in abeyance, and they will probably only be again undertaken should some special points of enquiry arise.

XVI. Summary, Papers to be Written, &c.

I have now given an account, as brief as the nature of the subject would permit, of the history, and of the present position, of most of the investigations which have been undertaken at Rothamsted; and, as it is supposed that the document will chiefly be of use for reference, and a full table of contents is provided at the commencement, it is believed that the amount of detail given will be an advantage.

In regard to my Oxford Lectures, it may be stated,

that the appointment was accepted with the special view of utilising the occasion for the preparation for publication, in a collective, systematic, and useful form, of an account of the then more than 40 (and now nearer 50) years of investigation, in conjunction with Sir J. B. Lawes, at Rothamsted; and although I have not neglected important results and conclusions of others, I have, as my Syllabus shows, fully utilised the occasion as was proposed.

The Syllabus further shows, that much of the matter dealt with had previously been published in detail, but that a considerable amount of new matter has also been arranged and studied for, and more or less discussed in, the Lectures. There is thus provided the basis for several systematic papers. In all cases, whether the subjects had previously been reported upon in detail or not, they have been brought, in the lectures, into collective form and order.

Six of the courses of Oxford Lectures have been summarised, each into one lecture, given at the Royal Agricultural College, Cirencester, and these single lectures have been published (with some additions) as under:—

1. On Wheat, in No. 68 .. .. .. 1884.
2. On Barley, in No. 71 .. .. .. 1886.
3. On Root-crops, in No. 76 .. .. .. 1887.
4. On Potatoes, in No. 78 .. .. .. 1888.
5. On Leguminous Crops, in No. 81 .. .. 1889.
6. On the Fixation of Free Nitrogen, in No. 84 1890.

I will now point out what seems to be the proper order of publication on other subjects, within the comparatively near future.

1. As already referred to (p. 52), a "Preliminary Notice" of the results of the experiments made at Rothamsted in 1888 and 1889, on the lines of those of Hellriegel and Wilfarth, to determine whether the free nitrogen of the atmosphere contributes to the nitrogen of certain plants, under the influence of suitable microbe infection of the soil, was published in the "*Proceedings of the*

Royal Society" early in 1890; but it is hoped that this will soon be followed by a full report, bringing the record up to date.

2. Part III—*The Chemical Results*—in connection with the subject of the experiments on the Mixed Herbage of Grass-land. This will be a long joint paper, and it is expected that it will be ready for publication in the course of the present year, 1891.

3. The Experiments on Rotation; including both the Field results, and those of the Laboratory investigations connected with them. This will also be a long joint paper; and it should follow next in order to No. 2.

4. Probably the results relating to the composition of Animal manure, in relation to that of the food consumed.

5. Continuation of report on the Ensilage Experiments.

Besides these subjects, the preparation for publication, of the matter of the Oxford Lectures (which, however, will not appear in the form of lectures), should not be long delayed, and should, indeed, if possible, proceed concurrently with that of the papers above enumerated.

Other subjects will probably arise from time to time, which will require attention; and, as has been pointed out, the continuation of systematic reports will, in the course of time, have to be considered; as for example—on the Wheat experiments, after 40 years, commencing with 1852, or after the first 50 years, or after the third period of 20 years; on the Barley experiments, after the second period of 20 years; on the amount and composition of Rain and Drainage Waters—say in 10 years after the last publication. These, and other subjects, as has been indicated, will also be brought up to date, in more or less detail, in the work embodying the substance of the Oxford Lectures.

In conclusion, I may add that, of more than 700 complete ash-analyses that have been made, some have

been published in detail, some only partially, and others remain to be considered. The following have been fully written upon, and published:—

40	connected with animal composition (No. 29, Series 2).
253	of Wheat Grain and Wheat Straw (No. 65, Series 1).
20	of Potato Tubers and Juice .. (No. 78, Series 1).
313	

Of 88 analyses of the ashes of Barley Grain and Barley Straw, the greater number have been arranged, and partly written upon, in the Oxford Lectures; and the results and discussion have been summarised in No. 71.

Of 145 analyses of the ashes of the Mixed, or the Separated Herbage, of Grass-land, most have been arranged, and partly written upon, in the Oxford Lectures; and they will be fully discussed and published, in "Part III—*The Chemical Results*"—above referred to.

60 analyses of the ashes of the Rotation produce, and 8 of the ashes of Bean-plant, are written upon in the Oxford Lectures; and they will be fully discussed and published in the paper on the Rotation Experiments.

There are 68 analyses of the ash of Bean-corn and Bean-straw, the results of which will probably also find appropriate place in the report on the Rotation Experiments; or they may be embodied in the Work founded on the Oxford Lectures, in the section relating to "Leguminous Crops;" or they may receive separate consideration in due course.

Lastly, there are 32 partial analyses of the ash of Sugar-beet juice, which may perhaps be embodied in the Work on the matter of the Oxford Lectures, in the section relating to Root-crops, if not otherwise arranged for.

APPENDIX.

The following lists give the titles of Rothamsted papers already published, arranged in two Series, and within each Series numbered in chronological order. They also show, both where each paper originally appeared, and the date of its publication.

SERIES I.—*Reports of Field Experiments, Experiments on Vegetation, &c., &c.*—

Published 1847–91 *inclusive.*

1. Agricultural Chemistry (Jour. Roy. Ag. Soc. Eng., vol. viii, p. 226) 1847
2. Agricultural Chemistry, Turnip Culture (Jour. Roy. Ag. Soc. Eng., vol. viii, p. 494) 1847
3. Experimental Investigations into the Amount of Water Given Off by Plants during their Growth, especially in relation to the Fixation and Source of their various Constituents (Jour. Hort. Soc. Lond., vol. v, p. 38) 1850
4. Report of some Experiments undertaken at the suggestion of Professor Lindley, to ascertain the Comparative Evaporating Properties of Evergreen and Deciduous Trees (Jour. Hort. Soc. Lond., vol. vi, p. 227) 1851
5. Agricultural Chemistry, especially in relation to the Mineral Theory of Baron Liebig (Jour. Roy. Ag. Soc. Eng., vol. xii, p. 1) 1851
6. On the Amounts of, and Methods of Estimating, Ammonia and Nitric Acid in Rain-water (Report of the British Association for the Advancement of Science for 1854) 1854
7. Report to the Right Hon. the Earl of Leicester, on the Experiments, conducted by Mr. Keary, on the Growth of Wheat upon the same land for four successive years at Holkham Park Farm (Jour. Roy. Ag. Soc. Eng., vol. xvi, p. 207) 1855

8. On some points connected with Agricultural Chemistry; being a reply to Baron Liebig's "Principles of Agricultural Chemistry" (Jour. Roy. Ag. Soc. Eng., vol. xvi, p. 411) 1855
9. On the Growth of Wheat by the Lois Weedon System, on the Rothamsted Soil; and on the Combined Nitrogen in Soils (Jour. Roy. Ag. Soc. Eng., vol. xvii, p. 582) 1856
10. On some points in the Composition of Wheat Grain, its Products in the Mill, and Bread (Journal of the Chemical Society of London, vol. x, p. 1) .. 1857
11. On the Growth of Barley by different Manures continuously on the Same Land; and on the Position of the Crop in Rotation (Jour. Roy. Ag. Soc. Eng., vol. xviii, p. 454) 1857
12. Report of Experiments with different Manures on Permanent Meadow Land, with Tabular Appendix (Jour. Roy. Ag. Soc. Eng., vols. xix, p. 552, and xx, pp. 228 and 398) 1858-59
13. Report of Experiments on the Growth of Red Clover by different Manures (Jour. Roy. Ag. Soc. Eng., vol. xxi, p. 178) 1860
14. On the Sources of the Nitrogen of Vegetation; with special reference to the question whether Plants Assimilate Free or Uncombined Nitrogen.—Abstract (Proceedings of the Royal Society of London, vol. x, p. 544) 1860
15. On the Application of Different Manures to Different Crops, and on their proper distribution on the Farm 1861
16. On some Points in connection with the Exhaustion of Soils.—Abstract (Report of the British Association for the Advancement of Science for 1861) 1861
17. On the Sources of the Nitrogen of Vegetation, with special reference to the question whether Plants Assimilate Free or Uncombined Nitrogen (Philosophical Transactions, part 2, 1861) 1861
18. Report of Experiments made at Rodmersham, Kent, on the Growth of Wheat by different Descriptions of Manure for several years in succession on the same Land (Jour. Roy. Ag. Soc. Eng., vol. xxiii, p. 31) 1862

19. The Effects of Different Manures on the Mixed Herbage of Grass Land (Jour. Roy. Ag. Soc. Eng., vol. xxiv, p. 131) 1863
20. On the Sources of the Nitrogen of Vegetation, with special reference to the question whether Plants assimilate Free or Uncombined Nitrogen (Jour. Chem. Soc., new series, vol. i; entire series, vol. xvi) 1863
21. Liebig and the "Mineral Theory" (note, extracted from a paper by Messrs. Lawes and Gilbert, Jour. Roy. Ag. Soc. Eng., vol. xxiv, part 2) 1863
22. Further Report of Experiments with Different Manures on Permanent Meadow Land (Jour. Roy. Ag. Soc. Eng., vol. xxiv, part 2) 1863
23. Report of Experiments on the growth of Wheat for Twenty Years in Succession on the same land (Jour. Roy. Ag. Soc. Eng., vol. xxv, parts 1 and 2) 1864
24. On the Selection of Artificial Manures for the Sugar-cane 1864
25. On the Accumulation of the Nitrogen of Manure in the Soil (Report of the British Association for the Advancement of Science for 1866) 1866
26. Preliminary Notice of Results on the Composition of Wheat grown for twenty years in succession on the same land (Report of the British Association for the Advancement of Science for 1867) .. 1867
27. On the Home Produce, Imports, and Consumption of Wheat (Jour. Roy. Ag. Soc. Eng., vol. iv, s.s., part 2) 1868
28. Exhaustion of the Soil in Relation to Landlords' Covenants, and the Valuation of Unexhausted Improvements (read before the London Farmers' Club, April 4, 1870) 1870
29. Scientific Agriculture with a view to Profit (read before the Maidstone Farmers' Club, Dec. 15, 1870) 1870
30. Reports of Experiments on the Influence of various Manures on different Species of Plants (Proceedings of the Royal Horticultural Society) 1870
31. Effects of the Drought of 1870 on some of the Experimental Crops at Rothamsted) Jour. Roy. Ag. Soc. Eng., vol. vii, s.s., part 1) 1871
32. Notes on Clover Sickness (Jour. Roy. Hort. Soc., vol. iii) 1871

33. Report of Experiments on the Growth of Barley for Twenty Years in Succession on the same land (Jour. Roy. Ag. Soc. Eng., vol. ix, s.s., parts 1 and 2) 1873
34. Unexhausted Tillages and Manures, with reference to the Landlord and Tenant (Ireland) Act, 1870 1874
35. On the more frequent Growth of Barley on Heavy Land (read before the London Farmers' Club, February 1, 1875) 1875
36. On the Valuation of Unexhausted Manures (Jour. Roy. Ag. Soc. Eng., vol. xi, s.s., part 1) 1875
37. Note on the Occurrence of "Fairy Rings" (Jour. Linn. Soc., Botany, vol. xv, p. 17) 1875
38. On some points in connection with Vegetation (Address delivered at South Kensington in the Chemical Section of the Science Conferences) .. 1876
39. On Rainfall, Evaporation, and Percolation (Proceedings of the Inst. of Civil Engineers, vol. xiv, part 3) 1876
40. Freedom in the Growth and Sale of the Crops of the Farm, considered in relation to the interests of the Landowner and the Tenant Farmer (Jour. Soc. Arts, December 14, 1877) 1877
41. Composition of Potatoes (Note—Jour. Roy. Hort. Soc., vol. v, part 5; Proceedings, p. xxxvii) .. 1878
42. On Nitrification; Reports of Experiments made in the Rothamsted Laboratory. (Part 1, Jour. Chem. Soc., January, 1878; Part 2, Jour. Chem. Soc., July, 1879; Part 3, Jour. Chem. Soc., December, 1884; Part 4, Jour. Chem. Soc., 1891). See also —Rep. Brit. Ass., 1881; Jour. Chem. Soc., October, 1885, February, 1887, and August, 1888 1878–91
43. Is Higher Farming a Remedy for Lower Prices? (Lecture delivered before the East Bewickshire Agricultural Association, May 3, 1879. Published by G. Macaskie, "Warder" Office, Berwick) .. 1879
44. On the Determination of Nitric Acid as Nitric Oxide, by means of its action on Mercury; a Report of Experiments made in the Rothamsted Laboratory (Jour. Chem. Soc., July, 1879) .. 1879
45. On the Determination of Nitric Acid by means of Indigo, with special reference to Water Analysis; a Report of Experiments made in the Rothamsted Laboratory (Jour. Chem. Soc., September, 1879). See also Chem. News, February 2 and 9, 1877 1877–79

46. Agricultural, Botanical, and Chemical Results of Experiments on the Mixed Herbage of Permanent Meadow, conducted for more than twenty years in succession on the same Land. Part 1, The Agricultural Results. Abstract (Proceedings of the Royal Society, No. 197, 1879) 1879
47. On some points in connection with Agricultural Chemistry. Abstract (Report of the British Association for the Advancement of Science for 1879) 1879
48. Our Climate and our Wheat-Crops (Jour. Roy. Ag. Soc. Eng., vol. xvi, s.s., part 1) 1880
49. On the Home Produce, Imports, Consumption, and Price of Wheat, over twenty-eight (or twenty-seven) harvest-years, 1852–53 to 1879–80 inclusive (Jour. of the Statistical Society, June, 1880) 1880
50. Agricultural, Botanical, and Chemical Results of Experiments on the Mixed Herbage of Permanent Meadow, conducted for more than twenty years in succession on the same Land. Part 1, The Agricultural Results. Full Paper. (Philosophical Transactions, part 1, 1880) 1880
51. Sketch of the Progress of Agricultural Chemistry: Address to the Chemical Section of the British Association (Report of the British Association for the Advancement of Science for 1880) .. 1880
52. On the Determination of Nitric Acid as Nitric Oxide by means of its reaction with Ferrous Salts. Reports of Experiments made in the Rothamsted Laboratory. (Part 1, Jour. Chem. Soc., July, 1880; Part 2, Jour. Chem. Soc., August, 1882) 1880–82
53. On the Determination of Carbon in Soils; a Report of Experiments made in the Rothamsted Laboratory (Jour. Chem. Soc., September, 1880) .. 1880
54. On the Home Produce, Imports, Consumption, and Price of Wheat, over twenty-seven (or twenty-eight) harvest years, 1852–53 to 1879–80 (Jour. Roy. Ag. Soc., vol. xvi, s.s., part 2, 1880) .. 1880
55. Agricultural, Botanical, and Chemical Results of Experiments on the Mixed Herbage of Permanent Meadow, conducted for more than twenty years in succession on the same land. Part 2, The Botanical Results. Abstract (Proc. Roy. Soc., vol. xxx, p. 556) 1880

56. Letter on "Bread Reform" (Journal of the Society of Arts, January 21, 1881) 1881
57. On the Amount and Composition of the Rain and Drainage-Waters collected at Rothamsted, parts 1, 2, and 3 (Jour. Roy. Ag. Soc. Eng., vol. xvii, s.s. (1881), pp. 241–279, and 311–350; vol. xviii (1882), pp. 1–71). In the separate copies of the entire paper, section 3 of part 3 is given as part 4, and Appendix Tables are also added .. 1881–82
58. Letters on "Fertility" (Agricultural Gazette, Feb. 21 and 28; Mar. 7, 14, and 21; April 4, 11, 18, and 25; May 2 and 9, 1881) 1881
59. Some Practical Aspects of recent investigations on Nitrification (Journal of the Society of Arts, April 7, 1882) 1882
60. Determinations of Nitrogen in the Soils of some of the Experimental Fields at Rothamsted, and the bearing of the results on the question of the Sources of the Nitrogen of our Crops. (Read at the Meeting of the American Association for the Advancement of Science, at Montreal, August 1882) 1882
61. Agricultural, Botanical, and Chemical Results of Experiments on the Mixed Herbage of Permanent Meadow, conducted for more than twenty years in succession on the same land. Part 2, The Botanical results. Full Paper. (Phil.. Trans., part 4, 1882) 1882
61a. On the Determination of Nitric Acid in Soils (Jour. Chem. Soc., Aug., 1882) 1882
61b. On some of the changes which Nitrogenous Matter undergoes within the Soil (Lecture delivered at South Kensington, April 16, 1883) 1883
62. Contributions to the Chemistry of "Fairy Rings" (Jour. Chem. Soc., May, 1883) 1883
63. New Determinations of Ammonia, Chlorine, and Sulphuric Acid, in the Rain-Water collected at Rothamsted (Jour. Roy. Ag. Soc. Eng., vol. xix, s.s., part 2, 1883) 1883
64. The Nitrogen as Nitric Acid, in the Soils and Subsoils of some of the Fields at Rothamsted (Jour. Roy. Ag. Soc., Eng., vol. xix, s.s., part 2, 1883) 1883

65. On the Composition of the Ash of Wheat-Grain, and Wheat-Straw, grown at Rothamsted, in different Seasons, and by different Manures (Jour. Chem. Soc., August, 1884) 1884
66. Report of Experiments on the growth of Wheat for the second period of twenty years in succession on the same Land (Jour. Roy. Ag. Soc. Eng., vol. xx, s.s., part 2, 1884) 1884
67. On some points in the Composition of Soils; with Results illustrating the sources of the Fertility of Manitoba Prairie Soils (Brit. Ass. for the Advancement of Science, Montreal, September 2, 1884; Abstract—Rep. p. 686. Full Paper—Trans. Chem. Soc., June, 1885) 1884–85
68. On Agricultural Investigation; being a Lecture delivered at the Michigan State Agricultural College, Lansing, Mich., October 14, 1884; and at Rutgers College, New Brunswick, N.J., October 27, 1884 1884
69. Note on some conditions of the development, and of the activity, of Chlorophyll.—Abstract (Report of the British Association for the Advancement of Science for 1885) 1885
70. On the Valuation of Unexhausted Manures (Jour. Roy. Ag. Soc. Eng., vol. xxi, s.s., part 2) .. 1885
71. Results of Experiments at Rothamsted on the Growth of Barley for more than thirty years in succession on the same Land (Agricultural Students' Gazette, New Series, vol. iii, part 1) .. 1886
72. Remarques sur la relation qui existe entre les sommes de température et la production agricole (Archives des sciences physiques et naturelles, Troisième période, Tome xvi, No. 11, Novembre 15, 1886) 1886
73. The Home Produce, Imports, Consumption and Price of Wheat in the United Kingdom, Thirty-four Harvest-years, 1852–63 to 1885–86 ("The Field," February 12, 1887) 1887
74. A contribution to the Study of Well Waters (Jour. Chem. Soc., June, 1887) 1887
75. On the present position of the question of the Sources of the Nitrogen of Vegetation, with some new results, and preliminary notice of new lines of investigation.—Preliminary Notice (Proc. Roy. Soc., vol. xliii, p. 108) 1887

76. Results of Experiments at Rothamsted on the Growth of Root-crops for many years in succession on the same Land (Agricultural Students' Gazette, New Series, vol. iii, part 5) 1887
77. On the Present Position of the Question of the Sources of Nitrogen of Vegetation, with some new Results, and Preliminary Notice of New Lines of Investigation. Full Paper. (Phil. Trans., vol. clxxx (1889), B., pp. 1—107) .. 1889
78. Results of Experiments at Rothamsted on the Growth of Potatoes for twelve years in succession on the same Land (Agricultural Students' Gazette, New Series, vol. iv, part 2) 1888
79. The History of a Field newly laid down to Permanent Grass (Jour. Roy. Ag. Soc., Eng., vol. xxv, s.s., part 1, 1889) 1889
80. The Amount of Nitric Acid in the Rain-Water at Rothamsted, with Notes on the Analysis of Rain-Water (Jour. Chem. Soc., August, 1889) .. 1889
81. Results of Experiments at Rothamsted on the Growth of Leguminous Crops for many years in succession on the same Land (Agricultural Students' Gazette, New Series, vol. iv, parts 5 and 6) 1889–90
82. New Experiments on the question of the Fixation of Free Nitrogen—Preliminary Notice (Proc. Roy. Soc., vol. xlvii, p. 85) 1890
83. The Food of our Agricultural Crops (Jour. Roy. Ag. Soc. Eng., vol. i, t.s., part 1, 1890) 1890
84. Results of Experiments at Rothamsted, on the Question of the Fixation of Free Nitrogen (Agricultural Students' Gazette, New Series, vol. v, parts 2 and 3) 1890–91
85. Observations on Rainfall, Percolation and Evaporation at Rothamsted, with tabular results for Twenty Harvest-years (September 1 to August 31), 1870-71 to 1889-90, inclusive (Proceedings of the Inst. of Civil Engineers, vol. cv, part 3) .. 1891

SERIES II.—*Reports of Experiments on the Feeding of Animals, Sewage Utilisation, Ensilage, &c., &c.*—

Published 1849–85, *inclusive.*

1. Agricultural Chemistry: Sheep Feeding and Manure, part 1. (With Tabular Appendix in 1856.) (Jour. Roy. Ag. Soc. Eng., vol. x, p. 276) 1849
2. Report of Experiments on the Comparative Fattening Qualities of Different Breeds of Sheep—Hampshire and Sussex Downs (Jour. Roy. Ag. Soc. Eng., vol. xii, p. 414) 1851
3. Report of Experiments on the Comparative Fattening Qualities of Different Breeds of Sheep—Cotswolds (Jour. Roy. Ag. Soc. Eng., vol. xiii, p. 179) 1852
4. On the Composition of Foods in relation to Respiration and the Feeding of Animals (Report of the British Association for the Advancement of Science for 1852) 1852
5. Agricultural Chemistry: Pig Feeding (Jour. Roy. Ag. Soc. Eng., vol. xiv, p. 459) 1853
6. On the Equivalency of Starch and Sugar in Food (Report of the British Association for the Advancement of Science for 1854) 1854
7. Experiments on the Comparative Fattening Qualities of Different Breeds of Sheep—Leicesters and Cross-Breeds (Jour. Roy. Ag. Soc. Eng., vol. xvi, p. 45) 1855
8. On the Sewage of London (Journal of the Society of Arts, March 7, 1855) 1855
9. Letter on the Utilisation of Town Sewage (from the Report ordered by the House of Commons to be printed, August 3, 1857. Appendix xii, p. 477) 1857
10. Experimental Inquiry into the Composition of some of the Animals Fed and Slaughtered as Human Food. Abstract (Proceedings of the Royal Society of London, vol. ix, p. 348) 1858
11. Observations on the recently-introduced Manufactured Foods for Agricultural Stock (Jour. Roy. Ag. Soc. Eng., vol. xix, p. 199) 1858
12. Experimental Inquiry into the Composition of some of the Animals Fed and Slaughtered as Human Food (Philosophical Transactions, part 2, 1859) 1859

13. On the Composition of Oxen, Sheep, and Pigs, and of their Increase while Fattening (Jour. Roy. Ag. Soc. Eng., vol. xxi, p. 433) 1860
14. On the Composition of the Animal Portion of our Food, and on its relations to Bread. Abstract (Jour. Chem. Soc., vol. xii, p. 54).. 1860
15. Fifth Report of Experiments on the Feeding of Sheep (Jour. Roy. Ag. Soc. Eng., vol. xxii, p. 189) 1861
16. Report of Experiments on the Fattening of Oxen at Woburn Park Farm (Jour. Roy. Ag. Soc. Eng., vol. xxii, p. 200) 1861
17. Experiments on the Question whether the Use of Condiments increases the Assimilation of Food by Fattening Animals, or adds to the Profits of the Feeder (Edinburgh Veterinary Review and Annals of Comparative Pathology, July, 1862) .. 1862
18. Supplementary Report of Experiments on the Feeding of Sheep (Jour. Roy. Ag. Soc. Eng., vol. xxiii, p. 191).. 1862
19. The Utilisation of Town Sewage (Jour. Roy. Ag. Soc. Eng., vol. xxiv, p. 65).. 1863
20. On the Chemistry of the Feeding of Animals for the Production of Meat and Manure (read before the Royal Dublin Society, March 31, 1864) .. 1864
21. On the Sewage of Towns (Third Report and Appendices 1, 2, and 3 of the Royal Commission. Presented to Parliament) 1865
22. Report (presented to Parliament) of Experiments undertaken by Order of the Board of Trade to Determine the Relative Values of Unmalted and Malted Barley as Food for Stock 1866
23. On the Composition, Value, and Utilisation of Town Sewage (Jour. Chem. Soc., New Series, vol. iv; Entire Series, vol. xix) 1866
24. Food, in its Relations to the various Exigencies of the Animal Body (Phil. Mag., July, 1866) .. 1866
25. On the Sources of the Fat of the Animal Body (Abstract—Rep. Brit. Ass. for 1866. Full paper, Phil. Mag., Dec., 1866) 1866
26. Note—On Sewage Utilisation (Proceedings of the Institution of Civil Engineers, vol. xiv, part 3) 1876

27. On some points in connection with Animal Nutrition (Address delivered at South Kensington in the Biological Section of the Science Conferences).. 1876
28. On the Formation of Fat in the Animal Body (Journal of Anatomy and Physiology, vol. xi, part 4) 1877
29. Supplement to former Paper entitled—"Experimental Inquiry into the Composition of some of the Animals Fed and Slaughtered as Human Food"—*Composition of the Ash of the Entire Animals, and of certain Separated Parts* (Abstract —Proc. Roy. Soc., vol. xxxv. Full Paper—Philosophical Transactions, part 3, 1883) 1883
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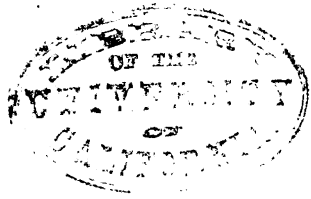

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